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SATELLITE COMMUNICATIONS FOR COAST GUARD HOMELAND DEFENSE

by

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SATELLITE COMMUNICATIONS FOR COAST GUARD HOMELAND DEFENSE

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ABSTRACT

The Coast Guard has developed a C4ISR infrastructure ashore to aid personnel in decision making, job performance, and information exchange, but in doing so they have neglected their most important asset; the afloat community. In an effort to explore and find a wireless connectivity solution for CG cutters, the authors examined the requirements for solutions in the area of commercial satellite connectivity. This connection is necessary for USCG afloat assets to access vital maritime, law enforcement, and Fisheries databases maintained ashore, as well as to keep those ashore informed of mission status. This connection also allows cutters to connect to CGDN+ and the Internet, improving both morale and personnel administration issues (leave, medical records, training, assignment process, etc.) With the technologies now available, the USCG must identify which solutions can best be utilized with respect to bandwidth, security, cost, equipment installation requirements, durability, and range. Primarily our research dissects Qualcomm's Globalstar satellite options, INMARSAT and capacity expander (ICE) technology, and current Navy INMARSAT technology solutions. The authors have identified technological limitations and proper requirement analysis techniques that will aid in future Coast Guard evaluations of these extremely high cost wireless networks. Finally, the authors make recommendations for near and long-term solutions to the Coast Guard's connectivity requirements.

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS

ACPO	Association of Public-safety Communications Officials
ADE	Above decks Equipment
ADMS	Automated Digital Multiplexing System
AES	Advanced Encryption Standard
AMPS	Advanced Mobile Phone Service
ANCC	Automated Network Control Center
AORE	Atlantic Ocean Region East
AORW	Atlantic Ocean Region West
APC	Adaptive Predictive Speech Coding
ASD C3I	Assistant Secretary of Defense Command, Control, Communications, and Information
ATM	Asynchronous Transfer Mode
ATO/MDU	Air Tasking Order/Mission Data Update
BDE	Below Decks Equipment
BER	Bit Error Rate
B-GAN	Broadband Global Area Network
BPSK	Binary Phase-Shift-Keyed
C2BST	Cutter Connectivity Business Solutions Team
C4I	Command, Control, Communications, Computers, and Information
CAMS	Communications Area Master Station
CAPS	Channel Access Protocols
CCC	CINC Command Complex
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CES	Coast Earth Stations
CGDN+	Coast Guard Data Network Plus
CJTF	Combined Joint Task Force
COMMERSAT	Commercial Satellite
COMMPLAN	Communications Plan
COMSATCOM	Commercial Satellite Communications Project
CPB	87' Coastal Patrol Boat
CRC	Cyclic Redundancy Check
CSS	Copernicus Communications Support System
CUDIXS	Common User Digital Information Exchange Subsystem
DAMA	Demand Assigned Multiple Access
DES	Data Encryption Standard
DISA	Defense Information Systems Agency
DISN	Defense Information Support Network
DLED	Dedicated Loop Encryption Device
DMR	Defense Management Report

DoD	Department of Defense
DON	Department of the Navy
DSCS	Defense Satellite Communications System
ECC	Encrypted Configuration Control
ECF	Earth Centered Fixed
EIP	Embedded INFOSEC Product
EIRP	Equivalent Isotropically Radiated Power
ELT	Enforcement of Laws and Treaties
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FLTCINC	Fleet Commander In Chief
FTE	Full Time Equivalent
FY	Fiscal Year
GBO	Globalstar Business Office
GBS	Global Broadcast Service
GDN	Globalstar Data Network
GENSER	General Service
GEO	Geosynchronous Earth Orbit
GLOBIXS	Global Information Exchange System
GMDSS	Global Maritime Distress and Safety Systems
GOCC	Ground Operations Control Centers
GOTS	Government Off-The-Shelf
GPS	Global Positioning System
GPTEE	General-Purpose Telegraph Encryption Equipment
GSM	Global System for Mobile Communications
HF	High Frequency
HSD	High-Speed Data
ICA	Integrated Communications Architecture
ICE	INMARSAT Capacity Expander
ICS	Integrated Communications System
IGO	International Government Organization
IMO	International Maritime Organization
INM	Integrated Network Manager
INMARSAT	International Maritime Satellite Organization
IOR	Indian Ocean Region
ISNS	Integrated Shipboard Network System
ISO	International Standards Organization
IT-21	Information Technology for the 21st Century
ITP	Integrated Test Plan
JMCOMS	Joint Maritime Communications Strategy
JTF	Joint Task Force
JTG	Joint Task Group
JWICS	Joint Worldwide Intelligence Communications System

Kbps	Kilobits per second
LAN	Local Area Network
LDR	Low Data Rate
LEO	Low Earth Orbit
MCU	Main Control Unit
MDA	Maritime Domain Awareness
MES	Mobile Earth Stations
MHz	Megahertz
MILSATCOM	Military Satellite Communications
MLE	Maritime Law Enforcement
NATO	North Atlantic Treaty Organization
NCS	Network Coordination Station
NCTAMS	Naval Computer and Telecommunications Area-Master Station
NDI	Non Development Item
NDS	National Distress System
NEO	Noncombatant Evacuation Operation
NES	Network Encryption System
NMCI	Navy/Marine Corps Intranet
NOC	Network Operations Center
NSA	National Security Agency
OPCEN	Operations Center
OQPSK	Offset Quaternary Phase-Shift-Keyed
OSC	On Scene Commander
OSI	Open System Interconnection
PABX	Private Automatic Branch Exchange
PLMN	Public Land Mobile Network
PN	Pseudo-Noise
POP	Point of Presence
POR	Pacific Ocean Region
PSTN	Public Switched Telephone Network
QASPR	QUALCOMM Automatic Satellite Position Reporting
QOS	Quality of Service
QPSK	Quaternary Phase-Shift-Keyed
R&S	Routing and Switching
SALTS	Streamlined Automated Logistics Transmission System
SAR	Search and Rescue
SATCOM	Satellite Communications
SCCS	Shipboard Command and Control System
SCPC	Single Channel Per Carrier
SES	Ship Earth Stations
SHF	Super High Frequency
SOCC	Satellite Operations Control Centers
SRU	Surface Resource Unit

SSL	Secure Socket Layer
SU	Subscriber Unit
SURTASS	Surveillance Towed Array Sensor System
T&C	Telemetry and Command
TADIXS	Tactical Data Information Exchange System
TCC	Tactical Command Centers
TDMA	Time Division Multiple Access
TISCOM	Telecommunication & Information System Command
VHF	Very High Frequency
VIXS	Video Information Exchange Subsystem
VPN	Virtual Private Network
VTC	Video Teleconference
WAGB	Icebreakers
WAN	Wide Area Network
WHEC	High Endurance Cutter
WIX	Training Cutter
WLB	Seagoing Buoy Tenders
WLI	Inland Buoy Tenders
WLIC	Construction Tenders
WLM	Coastal Buoy Tenders
WLR	River Tender
WMEC	Medium-Endurance Cutters
WPB	Patrol Boats
WTGB	Icebreaking Tugs
WYTL	Harbor Tugs, Small

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I. INTRODUCTION

A. BACKGROUND

In the late 18th century, the newly independent United States of America recognized the need to protect its ports and extensive coastline early in the country's development. Alexander Hamilton published the quote below in the Federalist Papers during the fall of 1787.

> A few armed vessels, judiciously stationed at the entrances of our ports, might at a small expense be made useful, sentinels of the law. [Ref. 1]

That was the day the Coast Guard of today was conceived. Three years later, the service was born on August 4, 1790. Never has such a quote been so prophetic. At the time of this research, the Coast Guard has been tasked by the nation to judiciously station their sentinels at the entrances to our ports. From these concepts of Alexander Hamilton, the mission of Homeland Defense has grown.

The Coast Guard has always maintained Homeland Defense as one of its core missions. However, never has the mission received such attention as it has since the events of September 11, 2001. As a result of that terrible day, the Coast Guard has stretched its thin force in an attempt to post its vessels and enforcement units in every major US harbor.

B. HOMELAND SECURITY

Even before the September 11th terrorist attacks, the Coast Guard faced an array of maritime security challenges including environmental degradation, illegal migration,

over-fishing, drug smuggling, organized crime, arms trafficking, mass migrations, and proliferation of weapons of mass destruction. These dangers pose direct threats to American lives, property, safety, health, stability, and values. The Coast Guard is uniquely positioned to provide America with a versatile, multi-mission force to address security challenges in the maritime domain. To deal with transnational threats at sea, most of which have a significant law enforcement dimension to them, the U.S. cannot look solely to a military solution. Unconstrained by Posse Comitatus, the Coast Guard has broad law enforcement and civil authority, military capabilities, and a coastal and offshore presence to bring to bear against Homeland Security requirements. The Coast Guard is a proven coordinator that routinely works side by side with other federal, state and local agencies, as well as other US armed services, to eliminate threats to US maritime security.

In an effort to execute the Homeland Defense mission, the CG has deemed Maritime Domain Awareness (MDA) as a critical component. MDA requires adequate information, intelligence, surveillance and reconnaissance of vessels, cargo & people of law enforcement interest. Simply put, it is possessing total awareness of vulnerabilities, threats & targets of interest on the water. The maritime security environment must allow the Coast Guard to identify the unlawful without unreasonably disrupting the free flow of commerce. The crux of establishing and maintaining an accurate MDA is the communications capabilities of the organization. [Ref. 2]

C. CAPABILITIES

The ever-increasing operational reliance on information technology has demonstrated the poor means of connectivity that the Coast Guard currently maintains. There is only a minimal satellite communications architecture that is operational. This architecture consists of limited International Maritime Satellite Organization (INMARSAT) capability aboard only the largest of CG units. The smaller units are left with only voice communications. These communications utilize high frequency (HF), very high frequency (VHF), or cellular phones. These smaller units have no data capabilities.

The CG has divided its units into two groups based upon there capabilities. These two groups are Coastal and Deepwater. Those units that patrol inland of 50 miles of the coast are the Coastal force, and those that patrol greater than 50 miles offshore comprise the Deepwater force. The CG is currently involved in a re-capitalization effort of the Deepwater units. While the majority of the Homeland Defense operations are conducted by the Coastal units, there are currently no attempts to re-capitalize the force package and its capabilities.

D. DEEPWATER

The Deepwater Program seeks to renovate, modernize, and/or replace the CG's entire portfolio of Deepwater assets. The new force package will operate with an integrated system of surface, air, command, control communications, computers, intelligence, surveillance, reconnaissance and logistics systems. Rather than focusing on a specific class of cutter or aircraft, the CG has

focused on the capability to perform all of its federally mandated missions in the deepwater region. [Ref. 2]

With the focus on missions, the CG prepared a specification that describes the fundamental capabilities the service needs to carry out all its missions. For instance, the performance specification requires the capability to deploy boarding teams. However, it does not specify how these teams should be deployed (i.e. via small boat, aircraft, or other means). The benefit of this mission-based performance acquisition approach is that the industry teams that are competing to develop the Integrated Deepwater System of assets have tremendous leeway to leverage cutting edge technologies and processes in their design concepts. In addition, by including the full range of assets, that include cutters, aircraft, sensors, communications, and logistics, industry has the flexibility to develop the optimum mix of assets that comprise their Integrated Deepwater System with interoperability built-in from the start. [Ref. 2]

Three industry teams with production facilities throughout the United States are competing for the Deepwater contract. It will be awarded in the third quarter of Fiscal Year (FY) 2002 to a single team. A prime contractor will coordinate the efforts of subcontractors from shipbuilding, aircraft, technology, and infrastructure industries. While a final cost has not been announced, initial estimates of the contract are in the billions of dollars with just over $300 million allocated for FY 2002 alone. [Ref. 2]

E. RESEARCH QUESTIONS

The primary research question of this thesis is: "What is the best solution for CG units to support underway connectivity to CG information-based assets including CG intranet and Coast Guard Data Network Plus (CGDN+)?" The subsidiary research questions are:

- What are the current CG connectivity practices and capabilities?
- What are the satellite technologies available?
- Which solution provides the most simple and least intrusive installation?
- Which solution best addresses security concerns?
- Compare/contrast CDMA and TDMA multiplexing schemes with respect to bandwidth requirements, data throughput, bandwidth efficiency and commercial availability.
- Specifically compare INMARSAT, Globalstar and the Navy's Automated Digital Network System (ADNS) solutions.

F. SCOPE

The scope of this research focuses on the satellite connectivity of the Coastal Homeland Defense operations. While Project Deepwater is addressing the connectivity of the CG's offshore units, we will focus our research around the connectivity of the smaller units. Primarily, we will explore three possible solutions to provide the Coastal enforcement units satellite connectivity. For the purpose of this research, we have identified the Coastal units as any units operating cutters under the length of 110 feet. This also includes boarding teams that may be operating separate from an assigned cutter.

G. ORGANIZATION OF STUDY

This thesis is organized as follows. Chapter II follows the introduction and explores the operational requirements for connectivity. Chapter III explores INMARSAT as a connectivity solution. Chapter IV explores Globalstar as a connectivity solution. Chapter V contains information concerning the US Navy solution of ADNS. Chapter VI contains an analysis of the above-mentioned three systems. Chapter VII follows with our conclusions and recommendations.

II. OVERVIEW OF COAST GUARD CONNECTIVITY REQUIREMENTS

A. CURRENT PRACTICES AND CAPABILITIES

The Coast Guard is now at a turning point in its mission and capabilities life cycle. With the Deepwater proposal before Congress, the need has come to compare future communication needs to the current infrastructure. There are many emerging technologies that look promising, but finding the solution that provides for the necessary reach, range, responsiveness, and interoperability is the key to guaranteeing Coast Guard mission success. The Deepwater contract will reach into the billions of dollars, and part of that will be to ensure CG communication links to the shore take advantage of new technologies in order to increase throughput, security and reliability.

Coast Guard research personnel at both the Telecommunication & Information System Command (TISCOM) and the Research and Development Center (R&D Cen) have determined that 128 kilobits per second (kbps) connections will be required onboard our cutters in the near future to adequately support Coast Guard missions. [Ref. 3] Currently most Coast Guard cutters have INMARSAT-A stations onboard, but the limitation of this 1980’s analog technology (9.6 kbps) is fast being exceeded. Not only is the 64 kbps data rate the new INMARSAT-B stations provide not adequate, but also the dial-up costs are becoming more than the Coast Guard can justify to spend on this overtaxed system. Still, the Coast Guard is proceeding with its implementation.

The Coast Guard has taken a step towards the outsourcing of some communications capabilities to help offset the high costs of INMARSAT. [Ref. 4] Due to the finite bandwidth of HF and military satellite communications (MILSATCOM) systems and the austere budgetary climate within which the Coast Guard operates, we are seeing the Coast Guard shift from government-owned to contracted communications services. This random collection of outsourced capabilities has resulted in a wide disparity of communication capabilities between afloat assets that threaten to undermine reliability and effectiveness. In order to re-establish and maintain a high level of effectiveness, efficiency and responsiveness, we must develop, acquire and deploy a completely integrated, multi-mission, interoperable system of cutters, boats, aircraft, sensors, communications, and logistics systems.

1. Typical Communication Configurations and Security

The following chart shows the most common communications systems available aboard a typical Coast Guard Cutter 210 foot in length and larger. These assets include: High Endurance Cutters (WHEC), Medium-Endurance Cutters (WMEC), Icebreakers (WAGB), and the Training Cutter (WIX)

MILSATCOM (UHF)	Secure Voice, Record Message Traffic, Tactical data (OTIXICS)	75-110 bps	None
INMARSAT-A (Analog)	Non-secure & Secure Voice, Data (e-mail via SALTS[1])	9600 bps	~$5/min
INMARSAT-B (Digital)	Non-secure & Secure Voice, Data (w/ HSD[2] option – CGDN+ connectivity, e-mail, EAs[3], Intranet/Internet access)	9.6 – 64 kbps	~$2.5/min for voice and low-spd (9600) data ~$9/min for HSD (64Kbps) data ~$30K+/Month for leased circuit
INMARSAT-C (data only)	SAFETYNET (MIS[4] & Distress alert/response)	600 bps	Safetynet – Free Data - ~$.01/char
HF	Secure & Non-secure Voice, HF RATT[5] – Record Message Traffic, Tactical data	75 –300 bps	None

Table 1 Typical Communications Onboard 210’ and Greater Cutters [From Ref. 5, p.6]

This next chart shows the typical communication systems on board smaller Coast Guard patrol boats (less then 210 feet in length). These assets include: Patrol

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1 SALTS - Streamlined Automated Logistics Transmission System

2 HSD – High Speed Data

3 EA – Enterprise Architecture

4 MIS – Management Information System

5 RATT – Radio Teletype

Boats (WPB), 87' Coastal Patrol Boats (CPB), Seagoing Buoy Tenders (WLB), Coastal Buoy Tenders (WLM), and Icebreaking Tugs(WTGB).

MILSATCOM (UHF) – limited 110's	Secure Voice	N/A	None
INMARSAT-C (data only)	SAFETYNET (MIS & Distress alert/response); data (e-mail via internet)	600 bps	Safetynet – Free Data - ~$.01/char
HF	Secure & Non-secure Voice, HFDL[6]– Record Message Traffic	300 - 600 bps	None
INMARSAT-Mini-M (currently locally obtained and managed)	Non-secure & Secure Voice, Data (e-mail)	2400 bps	~$2.15/min
Cellular (currently locally obtained and managed)	Non-secure voice, Limited data (CDPD[7], Ricochet, etc.)	2.4 – 19.9 kbps (typical)	Varies widely. CDPD ~$50/month + per min chgs + $1-2K in Hardware
VHF- FM data	Data (Great Lakes only, record message traffic)	300 bps	None

Table 2 Typical Communications on Smaller Coast Guard Vessels [From Ref. 5, p.7]

Currently, systems generally access the CG network either through dedicated circuits that the CG installs or

6 HFDL – High Frequency Data Link

7 CDPD - Cellular Digital Packet Data

the Internet at CG established Points of Presence (POP’s). These connections are required to be encrypted with a 128-bit secure socket layer (SSL) encryption standard (or greater) to protect the unclassified data outside the network. The systems must also be able to authenticate the users through either a remote access token or the router-to-router authentications (CHAP). One drawback to this security issue is the overhead associated with the encryption on an already bandwidth-constrained connection. Unfortunately, this is an unavoidable drawback to securing Coast Guard communications.

2. Stovepipes

Today’s CG communications system for cutters deployed at sea is a collection of discrete, special purpose networks. Each network has been developed and allocated for a specific communications capability for a specific community of users. Each network link is, in general, dedicated to the specific user community. The nature of these network links conforms to the traditional circuit switched approach. For example, General Service (GENSER) recorded message traffic is transmitted and received via the Common User Digital Information Exchange Subsystem (CUDIXS) network. This network subsystem requires a dedicated satellite channel, baseband communications processor, and shore-based network controller. No other type of traffic (voice or data) can be transmitted via this network or be processed by the CUDIXS subsystem. Loss of a satellite channel for any reason requires manual actions by personnel to re-route the traffic; it cannot be done automatically by software or hardware. Due to the narrow vertical architecture of this type of system it is termed a

“stove pipe” architecture. [Ref. 3, p.19] These vertical architectures significantly limit the flexibility, survivability, and growth potential of CG communications subsystems. These systems need to be more horizontally connected and less independent, thus sharing the limited resources available. For this reason the CG needs to focus attention on a single, shared, composite communications resource. Sharing individual resources will permit more efficient use of the relatively scarce communications assets onboard CG vessels. [Ref. 3, p.19]

By supporting different platforms throughout the CG fleet, we increase the complexity of the network, and thus increase the number of expert technicians required to maintain these systems. Furthermore, these stovepipe architectures are not interoperable, thus causing redundant data entry and data duplication. Other critical limitations include the following:

- The present communications system is “fragile” under conditions of stress. If a particular communications resource is lost, it is difficult to reconfigure other communications resources to compensate for this loss.
- The communications systems are not interoperable, thus it is difficult to rapidly route data between the systems.
- The architecture cannot respond to imbalances in the traffic load. One communications resource may be under-utilized while the capacity of another is being exceeded.
- It is difficult to respond to the changing communications requirements of current users, or to the requirements of new users.
- Since each communications system has unique hardware and software, life cycle support costs are high.

- The lack of overall systems approach makes it impossible to perform system level diagnostics or to provide automated assistance to operational personnel. [Ref. 3, p.3]

To help eliminate these inadequacies, the Coast Guard must get a grip on the implementation of small narrowly focused projects. The elimination of the “stovepipe” approach to communications is the target of the USCG’s vision. To incorporate this, Coast Guard goals must include:

- Increased communications survivability via automated multimedia access by all users to all media, without sacrificing user throughput or communications efficiency.
- Provide a means for incorporating new communications capabilities without requiring changes to the user equipment or operating procedures.
- Maximize the use of existing communications equipment.
- Phased development efforts of planned programs to allow timely transition of proven concepts. [Ref. 3, pp.3, 4]

In order to re-establish and maintain a high level of effectiveness, efficiency and responsiveness, we must develop, acquire and deploy a completely integrated, multi-mission, interoperable system of cutters, boats, aircraft, sensors, communications and logistic systems. [Ref. 6, p.8]

3. Coast Guard Research Efforts

A recent study by the Cutter Connectivity Business Solutions Team (C2BST) has established many of the baseline requirements for future cutter connectivity. [Ref. 5, p.4] It has been recognized that the communications equipment in the Tables 1 and 2 no longer provide CG cutters with

adequate communications to other Coast Guard assets and the terrestrial-based infrastructure. The following questions were considered when establishing the capability requirements of CG afloat assets: [Ref. 5, p.5]

- What enterprise applications (EAs) did the cutter need network access to while underway?
- Are operational systems included in this solutions set?
- What are the bandwidth requirements of the applications?
- Given limited bandwidth, what are the system priorities?

Progress is being made to upgrade and establish trustworthy connections between the afloat fleet and the terrestrial-based infrastructure. Currently the Commercial Satellite Communications Project is replacing older INMARSAT-A (analog) equipment with digital, high-speed capable INMARSAT-B (digital) systems. But at $9 per minute, and only 64 kbps of bandwidth, INMARSAT-B does not meet Coast Guard budgetary or bandwidth needs. Although this is a step forward, it is only being installed on the larger (210's and greater) CG cutters, thus still neglecting the majority of the fleet. To alleviate this, the C2BST is also working to replace the High Frequency Data Link (HFDL) on smaller cutters with a commercial product. The new COTS application runs on Windows NT[8] and will provide more reliable data transfer as well as a satellite terminal for secure/non-secure voice. These vessels, as well as the 87' Coastal Patrol Boat (CPB's),

[8] This could be a huge problem in the not too distant future, because Microsoft has announced they will no longer support Windows 95, 98, ME or NT in 2002. These are just the type of NDIs the Coast Guard needs to stay away from.

are also getting INMARSAT Mini-M terminals to meet secure/non-secure voice communication requirements. As for the even smaller vessels and river-based assets, no current enterprise-wide data connectivity project is under way. These local area District offices are experimenting with Cellular Digital Packet Data (CDPD) systems, which provide cellular data and voice coverage when within ~20 miles of the coast.

In addition to the C2BST, the Commandant has also established the Integrated Communications Architecture (ICA). The ICA will work to integrate CG communications systems and help protect the CG from utilizing Non Development Item (NDI) components that are obsolete at the time of production and operation. NDI’s are a top concern and can only be reliably addressed through a true open architecture. The single key factor in open systems architecture is the definition, management, and communication of standards that specify interfaces, services and supporting formats for interoperability of software and hardware systems. The benefit of employing an open system architecture is the simplified integration of systems and components not native to the developed system. This benefit is realized during integration, but is even more evident throughout the product life cycle as system upgrades are made to accept new technologies or to replace outdated equipment. [Ref. 3, p.18]

In addition to an open system architecture, the Integrated Communications System (ICS) has realized the need to make satellite communications (SATCOM) capacity onboard a cutter available to all SATCOM users. [Ref. 3,

p.10] Allocation of the cutter's SATCOM resources needs to be shared on a priority basis in accordance with a Communications Plan (COMMPLAN), and this can only be accomplished utilizing an open architecture as described by the ICS. The ICS can provide automated network monitoring and management and assists operators in the assignment and control of communication equipment. The ICS is characterized by the following attributes:

- Communication requirements of various CG user communities are satisfied within a single system design.
- User mission area activities are not restricted to a specific communication service.
- The modular "open system" architecture utilizes "standards" to promote rapid configuration, system growth, and enhance overall system survivability.
- COMMPLANs provide users system control, allowing rapid and automatic system reconfiguration.
- Provide ease of system adaptability to technological advances. [Ref. 3, p.39]

This architecture can also be represented in a simple diagram as shown in Figure 1 below:

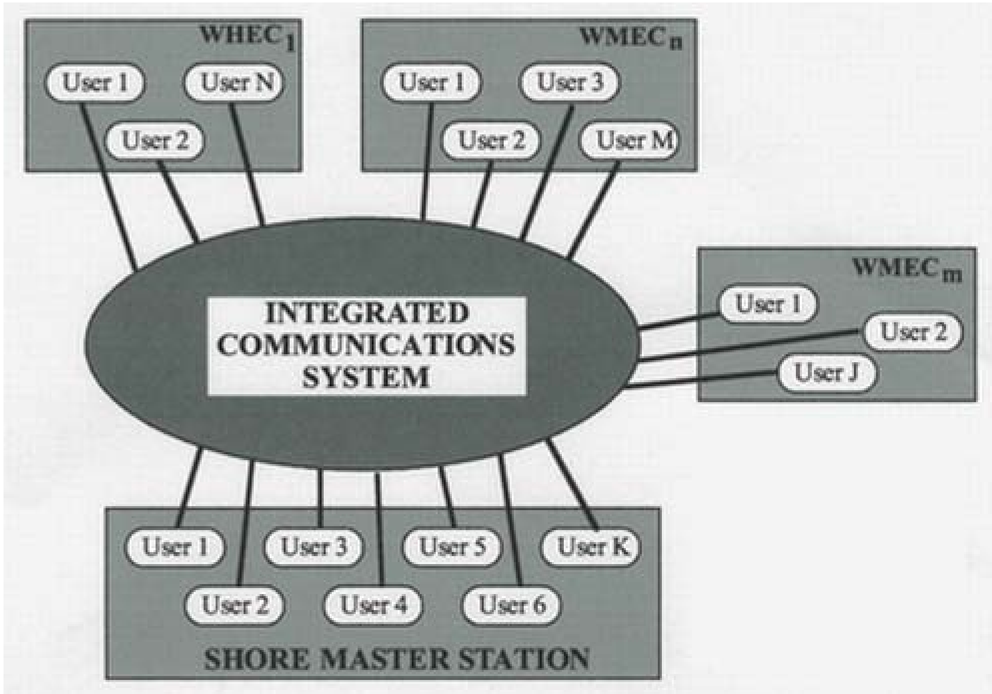

Figure 1. ICS Architecture Diagram

B. OTHER COAST GUARD CONCERNS

1. Phase-out of Traditional Communications Paths

One of the prime missions of the CG is Search and Rescue. In order to fulfill that mission, the CG monitors the National Distress System (NDS) frequency (CH16-156.8 megahertz (MHz)). The NDS provides distress, safety, and USCG command and control (C^2) communications coverage. The CG has been researching alternative communications systems for potential use in the modernization of the NDS. Currently the system consists of approximately 300 remotely controlled VHF frequency modulated (FM) radios and antennas [Ref. 7, p.3]. The major shortcomings of this system are similar to those of other CG and maritime communications: lack of coverage and lack of reliability. These two factors, along with accurate position reporting, are among the most important points for consideration when the CG is

analyzing a new system. Additionally, the International Cospas-Sarsat Program announced it would terminate satellite processing of distress signals from 121.5 and 243 MHz emergency beacons. Mariners and aviators will need to switch to the satellite-supported distress frequency 406MHz.

2. Interoperability

The ability to talk to anyone anywhere is becoming more and more of a necessity in the area of military operations. Coast Guard forces are required to make increasingly vital decisions in less time everyday. Within the area of Coast Guard operations, CG members may be required to work and communicate with Naval battle groups, U.S. Customs agents, local law enforcement agencies, DEA, FBI, Boarder Patrol, and the Secret Service. To sustain these diverse missions, the Coast Guard needs to support a broad spectrum of wireless communication abilities. At the current time when a Coast Guard cutter deploys with a Naval battle group, that cutter must undergo over a $1 million communications upgrade in order to meet USN requirements. Incompatibilities like these need to be avoided when the next generation of cutter communications equipment is installed.

To help meet these needs, the Coast Guard joined a joint government/industry standards group in 1995 to try to develop technical standards for the next generation of communications equipment worldwide. This has come to be called the APCO Project 25. Much of the work done by this committee is directly applicable to the CG’s interoperability issues. Due to the widespread acceptance

of the APCO 25 standards and their adoption as Federal standards (FTR 1024A), any new CG system needs to include compatibility with APCO 25 developments. They have focused on four key objectives:

- Obtain maximum radio spectrum efficiency.
- Allow effective, efficient and reliable intra-agency and inter-agency communications.
- Provide user-friendly equipment.
- Ensure competition in system life cycle procurements. [Ref 4, p. 3]

To help meet interoperability goals, the Coast Guard has gone ahead with prototyping and evaluating the Navy ADNS standard. This project adds additional equipment to standard CG SATCOM gear to provide simultaneous voice, secure (SIPRNET) and non-secure (CGDN+ or NIPRNET) data transfer capability via INMARSAT-B. The ADNS is part of the Navy's IT-21 system, which is the communications backbone that the fleet uses to stay connected in their network-centric battle model.

The ADNS implementation is closely tied to the Deepwater project, with one prototype in FY01 and potentially 3 more in FY02. ADNS uses a leased 64 Kbps channel and multiplexes both voice and data onto the same channel. The link uses the Navy Network Operations Center (NOC) as a hub for all classified/unclassified traffic. From the NOC, all CG traffic is further routed to a CG communications area master station (CAMS). [Ref. 5, pp.20, 21] Both the Navy's ADNS system and INMARSAT will be further evaluated in a later chapter.

C. HOW COMSATCOM WILL FACILITATE CG MISSIONS

The Coast Guard’s Commercial SATCOM initiative will provide funding for Coast Guard mobile units use of commercial SATCOM (COMSATCOM). It also supports maintenance and upgrades to the commercial satellite terminals installed on Coast Guard mobile assets. COMSATCOM can provide command, control, and communications (C3) of Coast Guard cutters and contingency forces, as well as interoperability with commercial vessels equipped with satellite communications in accordance with GMDSS.

Commercial SATCOM can support improved business practices by providing highly reliable, wide-area voice and data communications. Realizing this, future COMSATCOM initiatives are planned to provide a secure capability to this communication path. This will offset the rising cost of the current communications infrastructure, HF radio, and INMARSAT user costs through capital investment in new state-of-the-art technology.

Expansion of the commercial SATCOM path to aircraft will improve existing air-to-ground communications and allow elimination of personnel positions, which can be automated by this technology. By utilizing SATCOM technologies, CG users can currently direct-dial to any telephone on the public switched network using today’s existing INMARSAT capabilities. The upgrade initiative will replace (HFDL), which provides the 110’ cutter fleet with record message traffic, and will facilitate elimination of the HFDL positions at communications stations. Furthermore, SATCOM will directly benefit the Law Enforcement, Search and Rescue, Intelligence, and

Logistics programs by providing a rapid and reliable communications path at a reasonable cost.

Installation of satellite communications will provide the Coast Guard the first step towards possible retirement of significant HF-based infrastructure and substantial resource savings in personnel and support costs. The existing HF radio communications infrastructure is a poor communications path to support large data exchanges due to limited throughput. These limitations can be attributed to low power ratings leading to atmospheric loss and signal degradation, and also limited bandwidth within the HF spectrum. Use of new technology will allow the Coast Guard to take advantage of the cost savings resulting from competition in the commercial SATCOM market. This will allow the mobile platforms to utilize the commercial satellite communications path to its fullest potential at less cost per platform.

Data communications to accommodate tactical C2 and support needs is identified as a critical gap in the Coast Guard communications infrastructure as listed in the U.S. Coast Guard Command, Control, Communications, Computer and Intelligence (C4I) Baseline Architecture (COMDTINST 3090.6). This will become a larger problem in future Coast Guard operations due to an increasing need for information exchange to or from mobile units. This will also be hampered by the current inability of HF to support large digital data transmission rates due to insufficient bandwidth.

The Law Enforcement program is currently the largest user of INMARSAT. At least five of the critical gaps,

related to Law Enforcement communications capabilities identified in COMDTINST 3090.6, paragraph 9.5.1.1, can be bridged by installation of commercial SATCOM equipment on cutters and aircraft. These critical gaps include:

- The lack of reliable connectivity between cutters, aircraft and operational shore facilities, especially at extended ranges.
- The lack of an effective interface for exchanging information between larger Coast Guard platforms that support the Enforcement of Laws and Treaties (ELT) mission and Shore facilities (Districts) and smaller platforms (WPBs).
- The limited ability to effectively exchange sensor, intelligence and other tactical information between aircraft, mobile units and shore facilities.
- The lack of high speed, reliable communications between mobile assets and operational support information to assist in or which is mission essential for the execution of the ELT/Maritime Law Enforcement (MLE) mission.
- The generally cumbersome interfaces available for using Coast Guard Command and Control/Communications systems.

In addition to support of the LE mission, COMSATCOM can also be implemented to support the Search and Rescue mission: COMDTINST 3090.6, paragraph 4.5.1.1, identifies critical gaps in communications capability related to Search and Rescue (SAR) to which a commercial SATCOM capability would be a logical and cost-effective solution. Specific communications requirements, which could be addressed by commercial SATCOM, as listed in COMDTINST 3090.6 are:

- OPCEN controllers shall have secure or non-secure voice communications with On Scene Commanders (OSC).

- Conduct OCS functions, including coordination of Surface Resource Unit (SRU) response, monitoring of SRU performance, adoption of SAR Action Plan to on scene conditions and incident development, and communicating with the SAR Mission Coordinator in real time.
- Communicate in real or near-real-time, in all modes (Voice, data, video), with Coast Guard resources and all appropriate federal, state and local agencies and maritime public while conducting operations.

D. FOLLOWING INDUSTRY STANDARDS

In order to assure that future Coast Guard systems will maintain an easily upgradeable system without excessive reengineering, the Coast Guard needs to follow industry standards. Standards are in place establishing how Internets and Intranets are designed. These rules were set up to ensure one network technology is able to communicate with another network technology, thus making up the Internet. The ICS layered network architecture adheres to the International Standards Organization's (ISO) Open System Interconnection (OSI) 7-layer reference model for network design. Among numerous benefits, this allows data link and sub-network layer protocols to be designed and optimized for each specific signal area. Survivability is increased as the availability of multiple assets compensates for the vulnerabilities of any single circuit. [Ref. 3, p.40]

1. Internets and Intranets

An Internet is a set of protocols by which heterogeneous systems may communicate. Equipment, software, and applications from many different developers

simply agree to use these standard protocols while passing information to each other. Each end is said to be privately implemented. That means that one end of the Internet should assume nothing about the nature of the machine(s) at the other end. The CG has established a private network, an intranet called Coast Guard Data Network Plus (CGDN+), which has added secure gateways between existing CG shore based Local Area Network/Wide Area Network (LAN/WAN) networks. The wide area CG private network is implemented with public carrier circuits using permanent virtual circuits and link level encryption. [Ref. 3, p.88] It is to this exact network that the afloat community needs to establish a secure, constant, reliable wireless connection.

In order to maintain compatibility with standards within the OSI 7-layer model, the CG will need to implement technologies conforming to TCP/IP protocols.

a. Transport Control Protocol (TCP)

The transport control protocol (TCP) provides a reliable data communications service. TCP is connection-oriented in that it maintains a connection, or virtual circuit, between a pair of communications processes. TCP incorporates mechanisms to ensure reliability of the connections and to control the flow of data over interfaces. The TCP is implemented in accordance with MIL-STD-1778.

b. Internet Protocol (IP)

The IP network protocol permits data to be transmitted and received across networks. Unlike TCP, it is connectionless and neither checks data for errors nor

performs flow control. It provides the means to communicate across multiple networks. The IP is in accordance with MIL-STD-1777. [Ref. 3, p.91]

To ensure the CG can maintain these communications paths, the CG needs to ensure these standards are followed in order for shipboard LANs to get WAN access capabilities. This routing capability needs to be designed for dockside and afloat operations. Obviously, afloat operations require integration with both shipboard LANs and ship-to-shore wireless signal communications system. [Ref. 3, p.90]

E. SATCOM MEASUREMENT PARAMETERS

Much research needs to be done, and is being done, to establish defined criteria with which a system must conform to satisfy the vast array of CG operational requirements. The following is a list and description of the most commonly used evaluation areas:

1. System Technical Performance

A system needs to be analyzed by a hierarchal evaluation technique, since no one system will provide a total solution in the Coast Guard’s dynamic environment. System flexibility is intended to represent a system’s ability to support the full dynamic range of Coast Guard missions and environments. The “ability to support” can be characterized by the following twelve characteristics:

a. Coverage

Coverage is the geographic area in which a mobile user has access to the satellite system. Coverage can also be defined more stringently as the ability to focus required satellite capabilities when and where they are needed. The vendor typically provides a coverage diagram of

the service area. This could be a map or chart showing the geographic area in which the system operates. This area is composed of the "footprint(s)" of the satellite or satellites that make up the system. Exact coverage areas can be calculated using software and verified by field tests. [Ref. 8, p.7] The figure below shows the basic difference in footprint coverage for the three different satellite orbits.

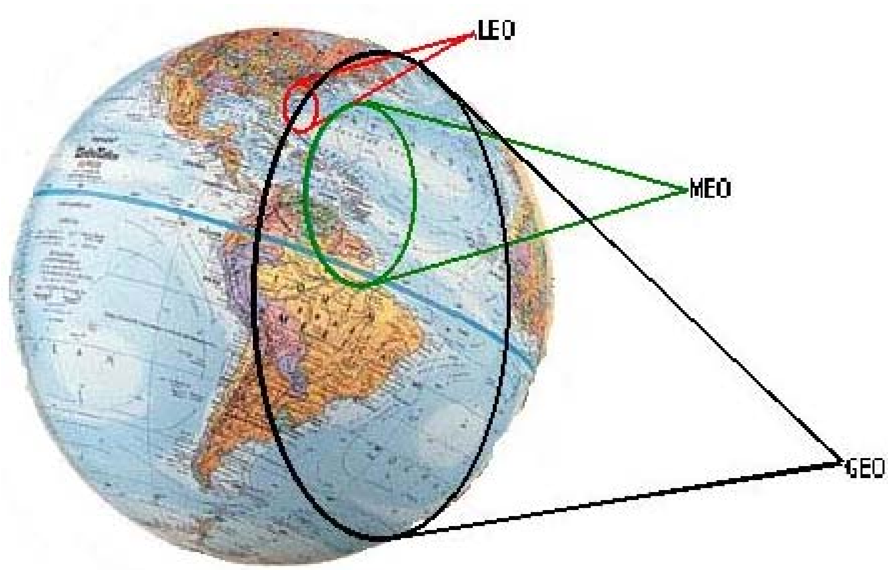

Figure 2. Representative Satellite Coverage Patterns [From Ref. 2]

b. Accuracy

Accuracy is a measure of the absence of error. Examples of accuracy in a voice or data system would be: Can you understand what the person is saying? Do you recognize his/her voice? Is the data sent on one end of the system the same as the data received at the other end? What is the Bit Error Rate (BER) for the system? These

parameters can all be measured in the lab or in the field. [Ref. 9, p.7]

c. Availability

Availability is the amount of unit time on any give day that the system is available for use. Reasons for non-availability could include: the traffic exceeds the capacity of the system, the system is temporarily out of service, or a satellite is not in view. Failure of user equipment would not be a reason for system non-availability. Prediction of the number of satellites in view and system availability can be calculated using satellite software programs, and can also be tested in the field or in labs. [Ref. 8, p.7] The C2BST has agreed that the Coast Guard would use 99.7% availability as the baseline requirement for connectivity. [Ref. 5, p.14] This means that the Coast Guard will accept 65.7 hours, or approximately 2.7 days, per year of unscheduled down time. The authors believe that a more stringent requirement of at least 99.9% be required. Doing this would require an unexpected downtime of less than 1 day per year (21.9 hours per year). Industry standards are already at 99.9% for network/server uptime and moving towards 99.999%.

d. Cost

This deals strictly with the costs associated with each system. These would include equipment costs and recurring service fees. Equipment costs would be life cycle costs such as: initial acquisition, installation, training and maintenance. These tend to vary for each mobile system. Recurring service fees would be the monthly access fees and usage fees based on airtime or the amount

of data sent. This data will be compiled based upon input from the system and service providers. [Ref. 8, p.7]

e. Interoperability

Interoperability is a measure of how well the system interfaces or integrates with existing systems. For example: Is it a circuit switched system that works with the Public Switched Telephone system? This would mean it might work like a telephone, fax or modem. Does it work like a packet switched system? How would we integrate it with existing Coast Guard systems? This can all be determined by lab testing. [Ref. 8, p.8] Interoperability is further described as the ability of systems, units, or forces to provide information services to, and accept information services from, other systems, units, or forces. It is then desired to use the services to enable them to operate effectively together.

f. Latency

Latency is the end-to-end delay in the system. In any transmission, this metric can be just as important as capacity or bandwidth of the channel. It is affected by a variety of things. The first and most obvious would be the length of the path. Other parts of the delay would be due to factors like the earth station location, buffering, system loading, and congestion. These factors can be measured in lab and field tests. [Ref. 9, p.8] This is the single largest hurdle to overcome with geostationary (GEO) satellite systems.

g. Reliability

Reliability is a measure of a system's dependability. This can be evaluated in the lab and in the

field by monitoring and recording equipment failures. It can also be obtained through the provider by researching past performance of equipment. [Ref. 9, p.8]

h. Capacity

Capacity is the maximum rate of reliable information transmission. This term is also sometimes used in conjunction with bandwidth. Bandwidth is the width of the communications channel from its highest operating frequency to its lowest frequency, and is an indication of how much information can be transferred by that channel. For analog voice, this would be measured in cycles per second, and for data or digital voice, this would be in bits per second. This is typically provided by the manufacturer, but can also be verified by lab testing. [Ref 8, p. 8]

i. Throughput

Throughput is the actual rate of traffic through the system and is dependent on many factors. A system may claim 64 kbps, like a 64 kbps modem used at home, but the user may only see 28-52 kbps (throughput) because of telephone line quality or other factors. Throughput available to users can and will be affected by terminal power, number of users (demand), latency, the required BER, and the security required. Figure 4 below shows how throughput is an end-to-end measurement of system effectiveness. As shown in the graphs, as the number of users, security requirements, or the required BER go up, the throughput of the system will go down. To offset this, as shown in the second graph, transmission (TX) and/or receiver (RX) power can be boosted in order to get more

throughput. This is not easily done with shipboard applications due to limited space and weight considerations.

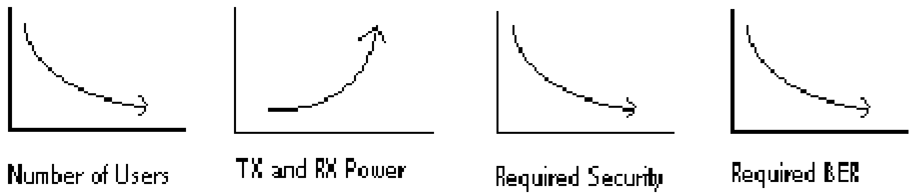

Figure 3. Throughput vs. variable parameters [From Ref. 4]

j. Ease of Use

How easy is the system to use and maintain? Is it like standard phones and PC's? Or would users have to learn new systems? [Ref. 8, p.8] Ease of use may be one of the most important evaluation criteria in deciding between two systems. No system is effective in support of missions unless personnel use it. Therefore, the technical depth required to operate the system needs to be kept to a minimum.

k. Security

Security involves how the system will protect the privacy and integrity of user data, as well as the network itself. Specifically, security is the ability of a system to avoid, prevent, negate, or mitigate the degradation, disruption, denial, unauthorized access, or exploitation of communications services by adversaries or the environment. This is typically done through some type of encryption scheme. There are three areas of security: authenticity, integrity, and data secrecy. Each system will have to be evaluated as to the level of security that is provided. [Ref. 8, p.8]

- **Data Secrecy** is often addressed by clearance levels (TS, S, C, U). This ensures only certain personnel has authority to view specific material.
- **Integrity** helps to prevent unauthorized modification, and ensure data accuracy.
- **Authenticity** is proven by assigning passwords, pins, and tokens. It proves your identity by something you know, something you have, or something you are (biometrics), often used in combinations. [Ref. 9, p.5]

l. Maintainability

Maintainability is defined as the "ability" of an item to be retained in or restored to a specified condition when personnel with the right skills perform the maintenance. [Ref. 8, p.8]

2. System Operational Performance

These metrics generally address how well the system helps the Coast Guard perform its missions. They generally are qualitative in nature and based on feedback from the users in the field. These 3 areas are used to establish overall standards on how well a system can/and will be used in aiding CG afloat/airborne assets. [Ref. 8, p.8]

a. Data Communications

Data communications consist of all text, database queries, and message traffic between two computers. [Ref. 8, p.8]

b. Real-time Position Location and Tracking

Automated position location will enable watch standers to know vessel/aircraft location, speed, and direction without waiting for updated position reports.

This will prove vital in the SAR and coastal Homeland Defense operations. [Ref. 8, p.8]

c. Protected Communications

Protected, or secure communications is the ability to transmit and receive voice, data, or video over a wired or wireless medium without the possibility of interception or modification from unwanted persons. This is mostly done through encryption of data and authentication of users. This also includes connections to SIPRNET and DMS. [Ref. 8, p.8]

Another criteria used during evaluation and comparison of each system performance is efficiency. Efficiency can be measured by the bandwidth provided compared to the bandwidth occupied. The closer this ratio is to one, the better the efficiency. Technology is always improving efficiency, so this is a measure of how easily the system will be able to take advantage of those improvements. [Ref. 8, p.8]

F. SUMMARY

Information collection and distribution are essential components of most CG missions; however, information needs have typically outpaced the ability of the installed communications systems to meet those needs. This mismatch leads to reduce effectiveness of CG operations. One current need is for CG aircraft to communicate information on vessels sighted to the shipboard commander quickly and efficiently. The shipboard commander needs to be able to access this information in real-time as well as retrieve related information from historical databases [Ref. 10, p.1]. In order to fully reap the benefits of a system that

would allow CG cutters and aircraft to maximize the use of resources based at shore-side facilities, there are four keys to success:

- Develop a system that is easy to modify as needed, keeping complexity at a central server
- Provide real-time response
- Give users only the information they need, when they need it
- Provide automatic data transmittal into the main CG law enforcement database (LEIS). [Ref. 6, p.3]

The next figure further expounds upon the previous diagram of the ICS, and incorporates with that a view of requirements and cutter connectivity needs. This figure helps to bring together the fact that mission, operational, and technical requirements need to be accounted for when choosing a communication technology.

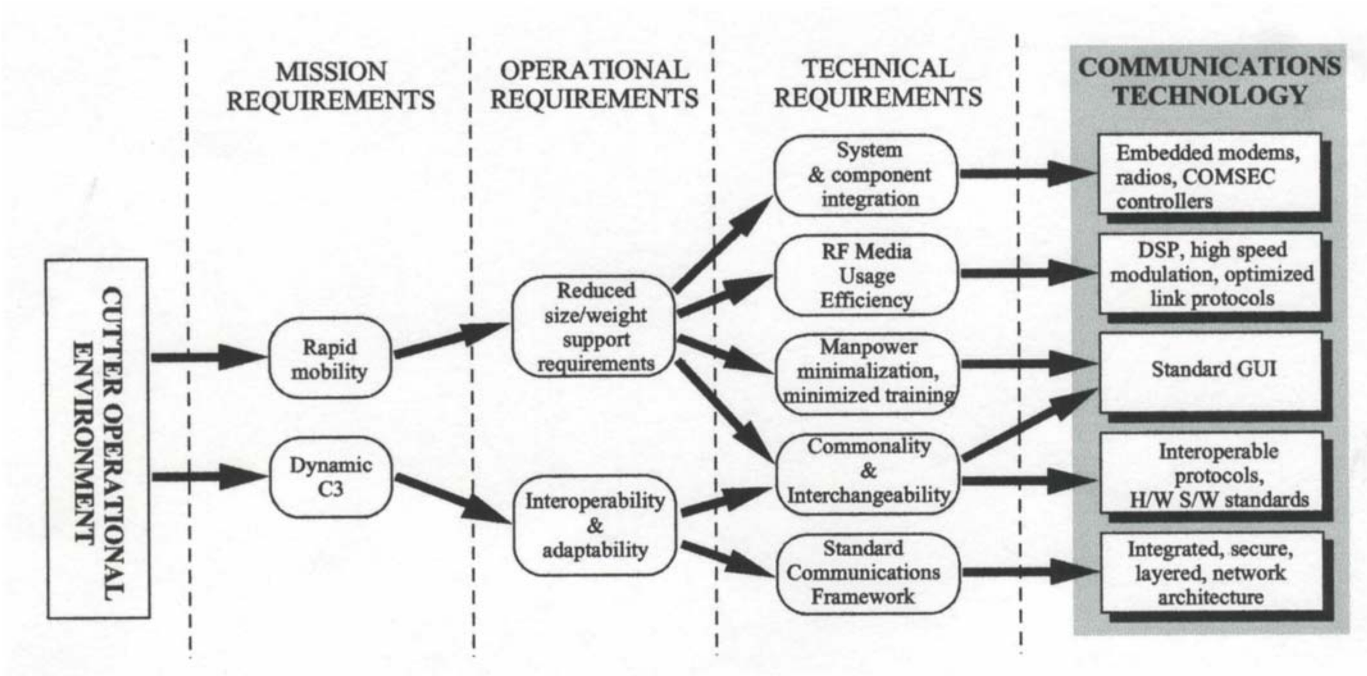

Figure 4. Critical path for communications systems [From Ref. 10]

As previously discussed in this chapter, the Coast Guard has tasked many teams to aid in the search for a communications solution for CG afloat and airborne assets. As has also been shown, CG current hardware is not capable of providing the desired capabilities that future missions will demand. The Coast Guard architecture has been built as a private network with specific, controlled access points (points-of-presence) to other private networks and the greater Internet. This has been done to afford the Coast Guard the ability to maintain CG own Intranet for CGWEB and enterprise architecture (EA) hosting as well as an enterprise-wide e-mail service.

When we compare the technologies that the R&D Center and TISCOM are currently exploring for connectivity

requirements to all CG cutters, all of the proposed solutions fall short to some degree. As a result, the Coast Guard is marching ahead with the new developments of INMARSAT-B, in an attempt to provide the bare minimum in order to get by. Unfortunately this comes at a very high price. [Ref. 5, p.25] Current stumbling blocks for proposed solutions include: heavy or large antennas, lack of commercial funding and further development of Low Earth Orbit (LEO) satellite communications, and a limited Coast Guard budget. Most of the solutions that have been tested could be made to work, but not necessarily as efficiently as the CG would like or can afford.

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III. INMARSAT

A. GENERAL OVERVIEW

The International Maritime Satellite Organizations (INMARSAT) was founded in 1979 as an International Government Organization (IGO). The IGO was tasked with providing a system of satellite communications for the maritime industry. The system was to provide fleet management, safety at sea, and distress response capabilities to the worldwide maritime industry. While INMARSAT continues to perform its original mission, it has since expanded its scope of service to include land, mobile and aeronautical applications to include telephony, high-speed data transfer, and data broadcast. In 1998, INMARSAT created a private company to compete in the handheld satellite telephone communications market. That company is known as ICO Global Communications.

1. History of INMARSAT

INMARSAT was established in July of 1979, as a measured response to satisfy the communications needs of the maritime industry. In 1966, the International Maritime Organization (IMO) undertook a study to identify a means of providing satellite communications for the maritime industry. The result of the study was a recommendation to utilize space communications techniques. This recommendation triggered the allocation of frequencies to the maritime mobile satellite service in 1971. IMO was tasked to be the lead agency for the project and convened an international conference of governments. After three

such international conferences, 79 member nations accepted and adopted the INMARSAT conventions.

INMARSAT established its headquarters in London and began providing ship management, distress and safety at sea services to the maritime industry in 1982. It later extended its focus to include aeronautical and land mobile operations. It has since provided telephone, telex, data and fax services to international shipping, aviation and land mobile operations. INMARSAT celebrated the installation of its 100,000th terminal in December 1997 and has experienced continued growth as interest in satellite communications continues to expand. [Ref 11, p. 25]

2. Space Segment

While INMARSAT has grown beyond the maritime industry, it has opted to maintain a space segment that is common to all its systems and applications. The space segment is composed of a series of satellites in circular, geosynchronous orbit in the plane of the equator. They orbit at a height of approximately 35,600 kilometers. INMARSAT has operated three generations of satellites and is currently making preparations for a fourth generation to be operational by 2004.

a. INMARSAT-1

INMARSAT’s first generation was a constellation of 3 satellites. These satellites and their services were leased from COMSAT, ESA, and INTELSAT. These satellites operated on a three-ocean-region configuration. Each satellite provided single global beam coverage.

b. INMARSAT-2

INMARSAT-2 satellites replaced the first generation satellites in the early 1990's. Unlike the first generation, these satellites were wholly owned and operated by INMARSAT. They were designed for a 10-year lifecycle. The major improvement INMARSAT-2 provided was it migrated to a four-ocean-region configuration with satellites located at 18.5 W, 55 W, 83 E and 180 E longitude. The four satellites' coverage areas were the Atlantic Ocean Region East (AORE), Atlantic Ocean Region West (AORW), Indian Ocean Region (IOR), and the Pacific Ocean Region (POR), respectively. With the increased global beam of the fourth satellite, INMARSAT could provide global coverage of the entire earth with the exception of only the extreme polar regions. When replaced by INMARSAT-3, INMARSAT-2 satellites were maintained in orbit to assume the role of in-orbit spares for the INMARSAT-3 constellation. [Ref 11, p.462]

INMARSAT-2 satellites utilize L-band for communications with ships and C-band for communications with shore stations. Each satellite utilizes an array of 61 elements to provide the global L-band beam. The satellites also contain two 7-element arrays to maintain the C-band connections, (one element each for transmission and reception). For shore-to-ship communications, one C/L-Band channel is used with a 16 MHz bandwidth. Ship-to-shore communications utilize four L/C-Band channels operating with 4.5 MHz bandwidths. These links are illustrated in figure 5. Each satellite has a total capacity of 250 two-way voice circuits. [Ref 11, p. 462]

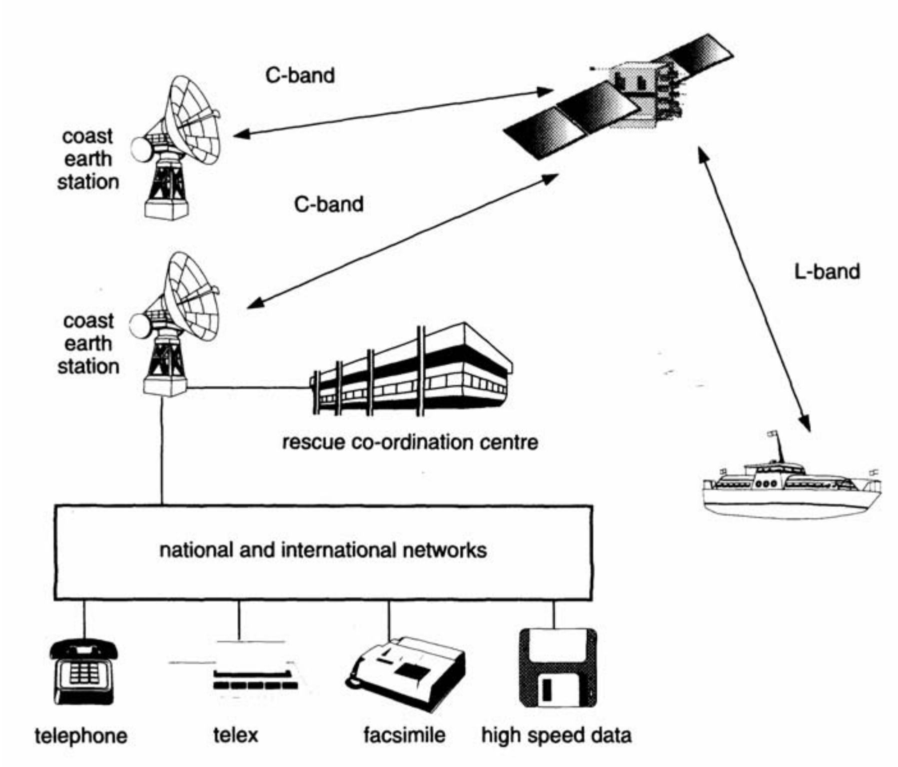

Figure 5. Typical INMARSAT Network [From Ref. 11, p. 463]

c. INMARSAT-3

INMARSAT’s third generation, INMARSAT-3, satellites were launched between 1996-1998 and are the current operating satellites for INMARSAT services. INMARSAT-3 was designed to provide a tenfold increase to system capacity and brought with it an increased communications payload. Each satellite operates one global beam as well as up to seven spot beams. These spot beams can be dynamically directed to provide increased coverage for areas of increased user demands. The satellites can re-allocate both power and bandwidth amongst the spot beams. This concept of spot beams has allowed INMARSAT to maintain constant coverage and service, regardless of user

demand. An example of the spot beams is illustrated in the figure below.

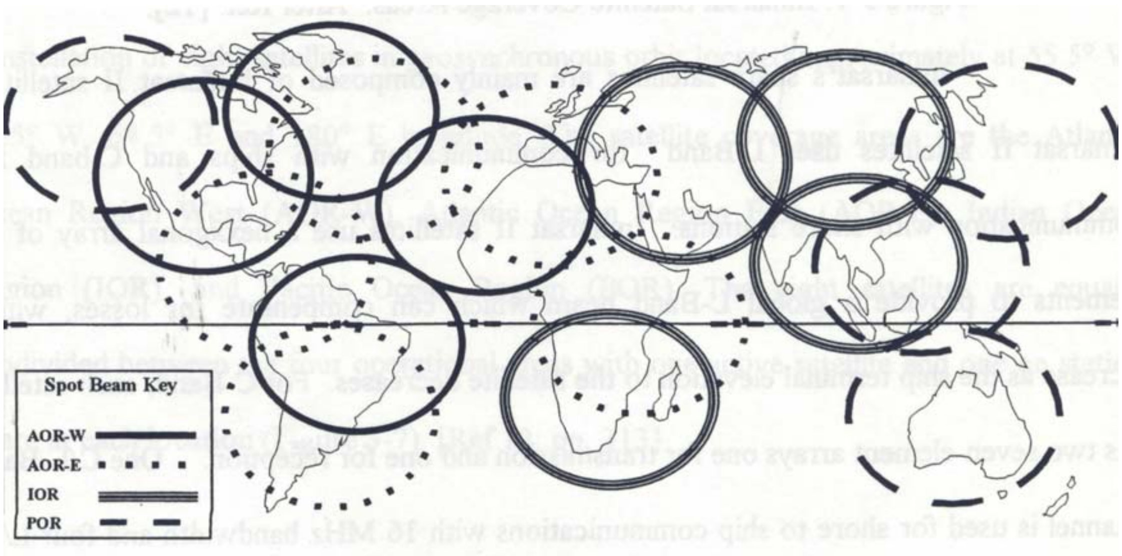

Figure 6.   INMARSAT spot beams [From Ref. 12]

INMARSAT-3 still utilizes the convention of maintaining a C/L-Band channel for shore to ship communications and an L/C-Band channel for ship to shore communications. Each INMARSAT-3 satellite can support up to 2000 simultaneous voice circuits. With the addition of the spot beams, INMARSAT-3 also provided the capability to support mobile personal communications services. These services utilize an L-Band to L-Band configuration and need only a laptop size terminal. The L-Band to L-Band mobile channel can provide 1 MHz of bandwidth. [Ref 11, p.462]

d. INMARSAT-4

Recognizing the growing market for high-speed internet access, corporate LAN access, and multimedia connectivity, INMARSAT is currently designing its fourth generation satellite, INMARSAT-4. INMARSAT-4 is being designed to be 100 times more powerful than the present

generation and to provide at least 10 times as much communications capacity as today's system. INMARSAT has awarded the contract to the European spacecraft manufacturer Astrium. The new generation will mark the launch of INMARSAT’s new Broadband Global Area Network (B-GAN). The system is planned to be operational in 2004. B-GAN will deliver internet and intranet content and solutions, video on demand, videoconferencing, fax, e-mail, phone and LAN access at speeds up to 432 kbps almost anywhere in the world. B-GAN will also be compatible with third-generation (3G) cellular systems.

B. INMARSAT A

The INMARSAT-A system was derived from the COMSAT MARISAT system, which became operational in 1976. The system was designed to provide circuit switched telephone and telex services between ships and the Public Switched Telephone Network (PSTN).

1. Land Segment

The land segment network consists of many ship earth stations (SES), several coast earth stations (CES) and the network coordination station (NCS). Each ocean area satellite space segment carries a similar terrestrial support network. Each ship installs the SES onboard that connects via L-Band frequencies to the space segment. The space segment then connects with the CES using C-Band frequencies. The CES performs the role of gateway to the PSTN. [Ref. 11, p.462]

2. Channel Assignment

The CES processes requests for the network received from either the SES or from the PSTN. For a ship

originated single channel per carrier (SCPC) call, a request message is received by the addressed CES. The CES then relays the request to the NCS for channel assignment. The NCS attempts to assign a channel in the appropriate spot beam. If no spot beam is available, a channel in the global beam is assigned. Once the channel assignment is made, the NCS broadcasts the assignment to both the CES and SES. For shore originated or PSTN calls, the CES requests the NCS to transmit a call announcement to the requested SES. Once the SES responds, the NCS makes the proper channel assignment to either a global or spot beam and transmits the assignment to both the CES and SES. [Ref. 13, p.3]

3. Antenna Requirements

One shortcoming of INMARSAT-A is that the terminals are rather large in size. This is a result of the limited power availability associated with the space segment. As the transmit power is tightly constrained, the antenna must become more powerful to achieve the signal strength required for a quality link. The system requires a significant equivalent isotropically radiated power (EIRP) value of at least 36dBW. In order to achieve such performance, the SES must utilize an antenna between 0.7 m and 1.0 m in diameter. By using such a large antenna, the SES must provide stabilization to account for the ship’s motion. A typical CES employs a large, 15-meter diameter antenna. [Ref. 11]

4. Cost

The above-mentioned factors all combine to create another shortcoming of INMARSAT-A, that of price. The

average price for an SES terminal is approximately $50,000. Another high cost item is the CES infrastructure. The CES costs are mostly attributed to the required access-control equipment. This equipment provides the demand-assignment functionality. Not only is each CES responsible for channel assignment as mentioned above, but also each must have the ability to operate independent of the NCS in the case of an NCS failure.

With the development and deployment of INMARSAT-B, INMARSAT-A has been rendered virtually obsolete. While the system is still operational, no new SES designs have been approved since 1989 for INMARSAT-A terminals. [Ref. 11, p.463]

C. INMARSAT-B

Design of INMARSAT-B began in the early 1980’s. The initial intent of the system was to reduce the cost of the SES terminal and improve the utilization of the satellite resources. After several years of development, INMARSAT-B is now operational and is often thought of as the digital version of INMARSAT-A. However, INMARSAT-B also included the technology for spot beams and an increase of services provided. In order to provide these additional features, INMARSAT-B protocols are much more complex than previous systems. INMARSAT has opted to apply the INMARSAT-B protocols across as much of future systems as possible, including the INMARSAT-M. This adoption of a single protocol is an attempt to enable the CES to use the same access-control equipment across all systems. [Ref 11, p. 464]

1. Services Provided

The majority of services provided by INMARSAT-B are still circuit switched. INMARSAT-B is able to not only provide the telephony and telex services provided by INMARSAT-A, but also low speed asynchronous data (300 bps), medium speed data services (9.6 kbps) and high-speed data services (64 kbps). In addition to these point-to-point services, the INMARSAT-B also facilitates shore-to-ship broadcast telex services for fleet management, safety and weather message distribution as well as network management services. The additional services also include a ship-to-shore distress alerting facility. These services satisfy the IMO requirements for the Global Maritime Distress and Safety Systems (GMDSS). Currently, INMARSAT is the only satellite provider to meet the GMDSS standards.

2. Voice Protocols

One of the new protocols included in INMARSAT-B is the employment of adaptive predictive speech coding (APC) for the telephony channel. This technique is further discussed below. The standard includes the use of APC at the rate of 16 kbps. The channel also includes a sub-band data channel that operates at 2.4 kbps. This channel requires the use of convolutional coding to achieve an acceptable bit error rate. INMARSAT-B utilizes 3/4 convolutional coding to achieve a transmission rate of 24 kbps. Convolutional coding is discussed later in this chapter. [Ref. 11, p.464]

a. Adaptive Predictive Speech Coding

Speech coding consists of complex algorithms that compress digital representations of speech signals to

minimize the number of bits required to represent those signals. They achieve this by taking advantage, to varying degrees, of redundancies in the speech signal and certain properties of the human hearing. Modern speech coding systems typically take advantage of the characteristics of the auditory system, the vocal tract and language. High quality is attained at low bit rates by exploiting signal redundancy. These systems also take advantage of the knowledge that certain coding distortions are masked by the signal and the relative phase insensitivity of the human ear. Speech coders often process speech in blocks, but block processing introduces communication delay. Depending on the application, the permissible total delay could be as low as 1 msec or as high as 500 msec. Communication delay is irrelevant for one-way communication, such as in voice mail or broadcast applications, but can be very detrimental in a network scenario. [Ref. 14] Most important is the fact that INMARSAT's communication delay is further hampered by the latency inherent with any geosynchronous satellite system.

b. Convolutional Coding

Convolutional coding is a technique widely used to provide some type of forward error correction (FEC) capability when transmitting over noisy or error prone channels. The purpose of FEC is to improve the capacity of a channel by adding some carefully designed redundant information to the data being transmitted through the channel. The process of adding this redundant information is known as channel coding. Convolutional coding is one of the major forms of channel coding to achieve FEC. Convolutional coders incorporate the memory of previous

input frames along with the new input data to determine the output. Convolutional codes are usually described using two parameters: the code rate and the constraint length. The code rate, k/n, is expressed as a ratio of the number of bits into the convolutional encoder (k) to the number of channel symbols output by the convolutional encoder (n) in a given encoder cycle. In the case of 1/2 convolutional coding, the input is a single bit and the output is two bits. The remembered frames are held in shift registers, and the encoding is carried out by a fixed pattern of additions on current and remembered bits to produce the output bits. The additions are exclusive-OR gates (modulo-2 adders). A typical schematic for a rate 1/2 encoder is shown in the figure below.

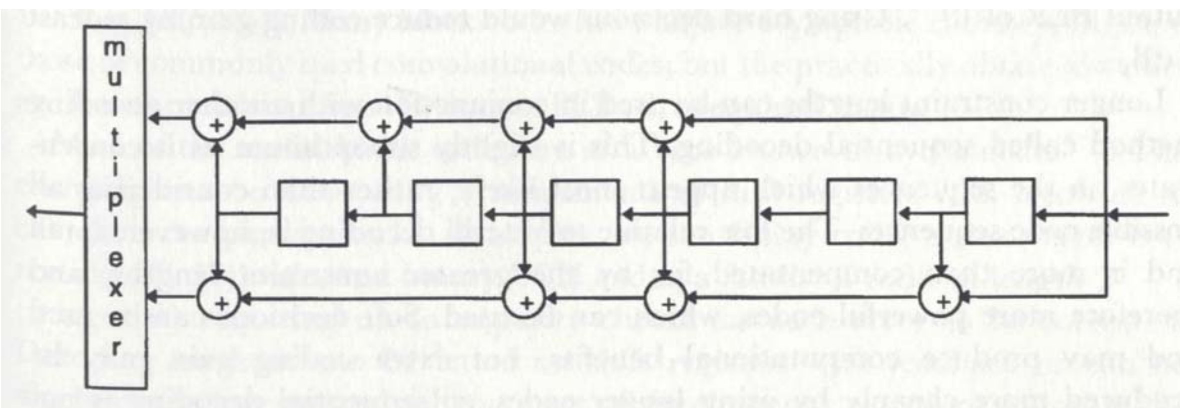

Figure 7. Convolutional Encoder [From Ref. 11]

INMARSAT utilizes Viterbi decoding for its convolutional codes. For years, convolutional coding with Viterbi decoding has been the predominant FEC technique used in space communications, particularly in geostationary satellite communication networks such as INMARSAT. The

most common variant used is rate 1/2 convolutional coding using a code with a constraint length K = 7. With this code, binary or quaternary phase-shift-keyed (BPSK or QPSK) signals can be transmitted with less. [Ref. 15] This is very useful in reducing transmitter and/or antenna cost or permitting increased data rates given the same transmitter power and antenna sizes, but there is a tradeoff. The same data rate with rate 1/2 convolutional coding utilizes twice the bandwidth of the same signal without it, given that the modulation technique is the same. This is a result of 1/2 convolutional encoding transmitting two channel symbols per data bit. The benefit is in the fact that if the modulation technique remains the same, the bandwidth expansion factor of a convolutional code is simply n/k.

3. Data Channels

As mentioned above, INMARSAT-B supports several levels of data transmission. They are telex, low-rate data, medium-speed data and high-speed data.

a. Telex and Low-rate Data

Both telex and low-rate data use TDM/FDMA for shore-to-ship communications and TDMA/FDMA for ship-to-shore communications. The system also has the option of utilizing a single TDM carrier to accommodate both telex and low-rate data functions when demand levels are low. The transmission rate provided for these services is 6 kbps utilizing a BPSK modulation scheme with 1/2 rate convolutional coding in the shore-to-ship direction. For ship-to-shore communications, the transmission rate is increased to 2.4 kbps and employs OQPSK modulation. [Ref. 11, p.464]

b. Medium-rate Data

The medium-rate data services are very similar to the telephony channel. The one major difference is the use of 1/2 rate convolutional coding vice the 3/4 rate used in the telephony channel. The convolutional coding and subband data channel work to provide 2.4 kbps data services.

c. High-speed Data

INMARSAT-B can support and provide a high-speed data service. INMARSAT defines its high-speed data as 64 kbps. In order to utilize this service, the subscriber has to upgrade the standard SES terminal. Independent of the data rate, the channel rate is 132 kbps. This channel rate is a function of 1/2 convolutional coding and some additional overhead generated by the data framing process. The service employs an OQPSK modulation scheme. The channel spacing is 100 kHz. The link budget is designed to provide a bit error rate of better than one error per 10^6 bits transmitted. [Ref. 11, p.465]

D. INMARSAT-C

INMARSAT-C was designed to address the growing need for land mobile service as well as to support the maritime industry. INMARSAT-C provides a low-speed, store and forward, two-way messaging service for both land and maritime applications. It also provides a broadcast message service that INMARSAT refers to as an enhanced group call. These broadcasts can be focused at the individual, fleet or geographical region level providing the shore facility a wide variety of fleet management

options. However, the more important use of this feature is to support the IMO mandated GMDSS. [Ref. 11, p.465]

1. System Benefits

INMARSAT-C was the first to be designed to use packet-switching techniques. The system configuration is similar to that of both INMARSAT-A and B with regards to both the land and space segments. One of the benefits of INMARSAT-C is that its low transmission speed of only 1.2 kbps enables a very low G_t requirement for the SES's. This also permits the use of un-stabilized antennas for the SES's. This results in a much smaller, simpler and significantly cheaper SES. These smaller SES terminals provide a more versatile system that can be installed on a variety of platforms including small vessels and vehicles.

2. Multiple Access Schemes

The NCS and CES units transmit on one or more carriers modulated at 1200 symbols per second using unfiltered BPSK. A TDM format is utilized to permit both fixed and variable length data packets. For the ship-to-shore communications, the SES's can transmit in one of two modes, dependent upon whether the system is transmitting a short message or signaling. A slotted-ALOHA scheme is utilized for signaling transmissions. For short messages, a TDMA scheme is employed using time-slot-reservation protocol. These access schemes are further discussed below. A third option is to assign a unique channel to a single SES/CES pair for longer message transmission. [Ref. 11, p.465]

a. Time-Division Multiple Access (TDMA)

TDMA is an access technique that allocates each user a periodic time slot. During this time slot, the user

transmits a burst of information on a common carrier. The common carrier is shared between all other users of the channel. The successive bursts from different users form a multiplexed TDMA frame at the satellite. Each burst needs to be highly time synchronized to eliminate any chance of burst overlap. A small guard time may often be inserted between each burst to also help guard against any overlap. The time slot allocation can be either a fixed or flexible, demand allocated scheme. An example of a TDMA frame is in the figure below.

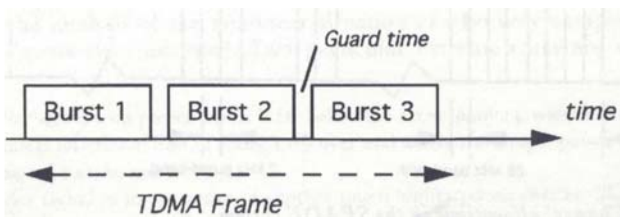

Figure 8. TDMA frame format [From Ref. 1]

TDMA carries with it several benefits and shortfalls. The first of the benefits is that only one carrier is being transmitted at one time. This permits the full power of the system to be available for transmission. This allows a TDMA scheme to achieve a higher overall EIRP than those systems utilizing other schemes such as frequency-division multiple access (FDMA). A fixed assignment TDMA scheme will also have a well-defined system capacity. This will help to enable proper system planning. One shortcoming of a TDMA system relates to the use of a single carrier. While the use of a single carrier permits the system to operate at a higher EIRP, it can also lead to inefficient operation. System power is wasted during empty slots that will occur when the network is lightly loaded.

The single carrier constraints prevent the unused power from being redistributed to other carriers in use, as an FDMA scheme would permit. Another shortcoming of the TDMA scheme is the need for very exact time synchronization between all segments of the network. Usually this involves timing bursts to be transmitted over the network by the master, or reference, earth station. This, coupled with any guard times in the TDMA frames will decrease the carrier availability for actual subscriber information transmission. [Ref. 16, pp.83-83]

b. Slotted ALOHA

One of the simplest random access schemes is the ALOHA protocol. Each station transmits a message whenever the need arises. The messages are transmitted as a data packet over a common channel shared by all other users of the network. Obviously, some transmissions will result in a collision of the packets. When a collision is detected the transmitting stations are notified and after a random delay, they each retransmit their packet. This process will continue until the packet is transmitted successfully. ALOHA protocols also use cyclic redundancy check (CRC) to detect any packet errors. CRC is a built-in error detection coding technique that uses a number of check bits appended to each data packet. If an error is detected, the packet is retransmitted until it is received successfully.

Slotted ALOHA is an enhanced version of the basic ALOHA protocol. In Slotted ALOHA, each data packet is the same size and constrained to begin and end at fixed and regular time intervals. This works to eliminate collisions caused by overlapping data packets and reduces the

retransmission requests on the network. One shortcoming of this protocol is that there are often unused portions of the channel. Another, more significant issue is throughput declines as the number of subscribers increases. Furthermore, the protocol also requires a high level of time synchronization across the network. As with TDMA, the time synchronization carries with it a heavy overhead to maintain. ALOHA protocols often include guard times to help eliminate any overlap. [Ref. 11, pp.151-152]

3. Land Segment

Aside from the small antenna, the INMARSAT-C terminal consists of a unit only a little larger than a desktop-PC modem. The terminal requires a less powerful antenna and an EIRP of only 12 dBW. The terminal also utilizes an RS-232 serial link consistent with other asynchronous data communication equipment. The requirements for the CES have been designed to match those of INMARSAT-A and B, allowing the CES’s to use the existing RF heads.

E. INMARSAT-M

INMARSAT-M is one of the newest technologies being developed by INMARSAT. It is being developed as part of a cooperative approach to include North America and Australia deployments. The cooperative approach is an effort to achieve a common global standard for M-type systems. INMARSAT-M was designed to provide mobile terminals that work in conjunction with the standard INMARSAT space segment. These new terminals are called mobile earth stations (MES) and are designed to provide medium quality telephony and full duplex, medium-rate data services. [Ref. 11, p.466]

1. MES Terminal Requirements

INMARSAT-M services support two types of MES terminals, one for land operations and one for maritime operations. The antenna for the land MES is a manually pointed phased array. The entire land MES terminal is about the size of a small briefcase. The maritime MES achieves the best results when a symmetric beam antenna is used with an actively stabilized mount. The stabilized antenna causes the maritime MES to be more expensive than its land counterpart. [Ref. 11, pp.466-467]

2. Transmission Signaling

The INMARSAT-M system is a circuit-switched network that operates with the INMARSAT-3 space segment. The MES is able to operate within both the INMARSAT-3 global and spot beams. The transmission channels are assigned using the same protocols as INMARSAT-A and B, utilizing the CES’s and NCS’s for each region as both a gateway and the network controller. The channels utilize an FDMA/SCPC scheme and a transmission rate of 8 kbps. The use of OQPSK enables the channel spacing to be reduced to 10 kHz.

a. Voice Transmission

INMARSAT-M provides only medium quality telephony services operating at a transmission rate of only 6.4 kbps. This rate includes vocoder and integrated forward error correction. The vocoder uses a voice-coding algorithm that uses a technique called improved multiband excitation (IMBE). The algorithm was developed by DVSI, Inc. In this technique, the speech is partitioned into frames, and each frame is analyzed to determine pitch and harmonic frequencies. The magnitude of the amplitude spectrum is

then coarsely quantized and encoded. The phase is not encoded. The decoding involves synthesizing sinusoids for the encoded frequencies and amplitudes, and carefully maintaining continuity of phase between one frame and the next. [Ref 8] The vocoder data is then multiplexed with subband data and framing information that operates at the rate of 1.2 kbps. The system then uses 3/4-rate convolutional coding. [Ref 11, p.467]

b. Data Transmission

INMARSAT-M also provides medium-rate data services. Operating in the duplex data mode, the information is combined with the subband and framing information. The data is then processed utilizing 3/4-rate convolutional coding. The coded symbols are then arranged into frames and transmitted at a rate of 8 kbps. The channel requires a satellite EIRP of no more than 17 dBW. [Ref. 11, p.467]

3. Mini-M

With the introduction of INMARSAT-3’s spot beam, a derivative of the INMARSAT-M system became operational late in 1996. The system became known as the mini-M. These terminals are slightly smaller than a full-M terminal. They are approximately the size of a laptop computer. The main difference between full and mini-M is that the voice-coding rate has been further reduced in the mini-M. The voice-coding rate was reduced from 6.4 kbps to only 4.8 kbps following the application of forward error correction techniques. Furthermore, the antenna gain was reduced to only 9 dB. [Ref. 11, p.468]

F. INMARSAT CAPACITY EXPANDER (ICE)

INMARSAT Capacity Expander (ICE) is a patent pending technology developed by Innovative Communications Technologies, Inc. (ICTI). ICE technology enables an improved means of point-to-point full duplex digital satellite communications using standard INMARSAT services. ICE is a COTS solution that improves the standard INMARSAT modulation, coding, signaling, duplexing and network management techniques to essentially double the throughput of a standard INMARSAT leased channel.

1. Channel Enhancement

While ICE technology is applicable to all standard INMARSAT services (A, B, mini-M) its possibilities are best realized when applied to a leased INMARSAT-B channel. A leased INMARSAT-B channel is an assigned frequency channel to which the subscriber has unfettered access. The subscriber does not have to compete for the channel as a user of the demand access system does. The leased channel provides 64 kbps when utilized with an upgraded SES terminal. [Ref. 17]

ICE technology has the ability to modify the SES system. A standard SES system will consist of the above decks equipment (ADE) and the below decks equipment (BDE). The ABE includes, but is not limited to, the RF terminal, antenna and RF power amplifier. The primary component of the BDE is the main control unit (MCU) that can be further broken down to include the SCPC modem, input ports and RF output. The modification of the SES system required by the ICE technology is the insertion of a passive element, the ICEBOX, between the BDE and ADE systems. The figure below

illustrates an example of an ICE equipped INMARSAT SES. [Ref. 17]

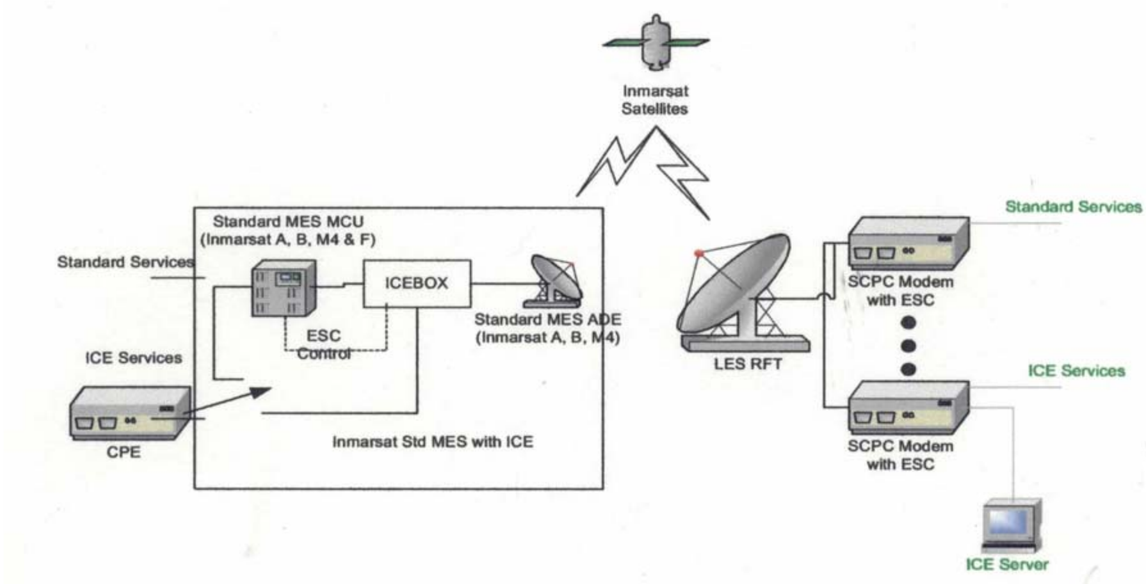

Figure 9. ICE equipped INMARSAT system [From Ref. 17]

The ICEBOX is composed of a duplexer, control processor and a second satellite modem. The duplexer combines the outbound signal for transmission and divides the inbound signals for demodulation. The satellite modem is equipped to utilize one or more advanced FEC coding schemes. The FEC coding schemes available for use are Viterbi, Sequential, Reed-Solomon, Trellis and Turbo. The modem also makes use of better modulation techniques (e.g., OQPSK or n-QAM) to achieve higher data rates. The FEC and modulation schemes are controlled remotely from an ICE-enabled NOC. They are dependent upon the bandwidth and data capacity assigned to each SES. [Ref. 17]

These system enhancements allow for better use of the 100 KHz channel allocation provided by a leased channel. The ICE system routinely will utilize approximately 96.3

KHz in comparison to standard INMARSAT-B, which utilizes only 76.8 KHz. This bandwidth efficiency, when joined with better coding and modulation schemes, allow the ICE to achieve much higher transmission throughput for a standard INMARSAT channel. The ICE system can essentially double the channel's throughput, from 64 kbps to 128 kbps with the standard 100 KHz channel. [Ref. 18]

2. Bandwidth Allocation

Another benefit of the ICE solution is that it can dynamically allocate the bandwidth of a leased channel between several ICE-equipped units. Assuming a 100 KHz leased channel, the ICE system can provide the equivalent of 128 kbps of throughput. It can further break this bandwidth out and assign segments to several units. An example of this would be to provide 32 kbps to 4 units, totaling the original 128 kbps. This is accomplished by the ICTI, Inc. network control center passing an Encrypted Configuration Control (ECC) message to each of the units sharing a single channel. The ECC message reassigns the channel's bandwidth and may alter each of the unit's coding and modulation schemes to achieve the desired assignment. ICTI, Inc. has proven they can allocate bandwidth in 32 kbps segments and claim they can achieve 16 kbps segment granularity. This reallocation can be achieved in only a few minutes, assuming all units are linked to the system. [Ref. 18]

3. Network Protocols

The ICE solution utilizes frame relay as a transport protocol. The use of the frame relay is intended to address several of the shortcomings of TCP/IP over a

geosynchronous satellite system. TCP/IP often struggles over such a link because of the large latency times involved with such a system. The frame relay protocol eliminates some of the three-way handshakes and acknowledgements utilized in TCP/IP in an effort to decrease retransmissions and increase the effective throughput of the system. [Ref. 19, p.213]

a. Frame Relay Protocol

Frame relay protocol is a network transportation protocol that is utilized to provide high-speed wide area network services. The protocol is often used for service in the long-distance telephone carriers’ networks. The protocol works to accept and deliver blocks of data on the network. Each block of data can be as large as 8,000 octets of data. The frame relay protocol is a connection-oriented service. This means that a connection must be formed and maintained between two nodes of the network before any information can be transmitted. This type of connection-oriented service is designed to best handle and deliver continuous data at a fixed rate. It is not the most efficient protocol for a burst-transmission traffic network. [Ref. 19, p.236]

b. Geosynchronous Satellite Latency

Latency can simply be defined as the time it takes a packet to travel from source to destination in the system. This is viewed as delay in a communications system and is one of the basic parameters when considering a system’s quality of service (QOS). Several applications cannot properly operate in situations of increased latency. For example, latency in voice communications becomes

noticeable when delays begin to exceed 100-200 msec. While small latency times will exist on the network, the average caller will not be able to distinguish a delay of smaller than about 100 msec in a phone conversation. For this reason, telephony applications demand that the system latency not exceed these parameters.

The latency is, in fact, the time it takes the signal to travel the entire distance of the network from the source node to the destination node. In terrestrial networks, this may be on the magnitude of several miles or even a few thousand miles. With these distances, today's transmission lines are able to transmit signals over the required distances with only minimal delays (on the order of tens of milliseconds). Problems arise when the signal is required to transmit via a geosynchronous satellite as a part of the network. The geosynchronous satellite is located approximately 36,000 kilometers above the earth's surface. This equates to an up and down travel distance of approximately 75,000 kilometers and incurs a system latency of approximately 250 msec. This latency already exceeds that required for telephony applications. In addition to this latency, further delay incurred by terrestrial network routing and connection solutions. For example, if one ship were calling another ship, only 500 yards away, via a standard INMARSAT terminal, the minimum delay under perfect conditions would be 250 msec. This incurs a noticeable and awkward time delay for voice communications. The problem is caused by the fact that the first ship is not simply calling the second. Each transmission must travel 36,000 kilometers to the satellite and 36,000 kilometers back to

the receiver. This is one of the downfalls of a geosynchronous satellite network.

The sizable latency incurred by a geosynchronous system also affects other aspects of a communications network. Latency has severe affects on any network client/server and transport protocols. Most network protocols are designed with a LAN in mind. By using the LAN as a network model, the protocol is designed under the assumption of only minimal round-trip delays. For this reason, the protocols are often designed using a series of low bandwidth request and acknowledgement exchanges. The sending and receiving nodes both transmit several signals either requesting data transmission or acknowledging the receipt of the data. Many protocols utilize a store and forward method of transport. This means that the sending node stores the data to be transmitted before transmitting. The node then transmits the data, retaining a stored copy. The sending node waits for a signal from the receiving node signifying that the data was received in an acceptable format. The original node waits a set time for the response message. If it does not receive the acknowledgement within that time it starts the entire process again. The original node will do this until it receives the acknowledgement message. It will also not move on to the next piece of data until it successfully sends the first.

With the above process in mind, it becomes obvious why the latency caused by a geosynchronous satellite system could cause severe problems for these protocols. Each transmission also requires at least one

response. That equates to 75,000 kilometers the packet must travel and 75,000 kilometers the acknowledgement must travel. These delays equate to a minimum system latency of 500 msec before the sender receives an acknowledgement.

TCP/IP is the protocol with which the internet and most LAN’s operate. It works similar to the generic protocol described above. For this reason, TCP/IP is often ineffective over a geosynchronous satellite network. One solution to the problem is to modify the protocol to wait a longer time for the acknowledgement message. The problem with that solution is TCP/IP is an end-to-end protocol. That means that you would have to modify the protocol on every computer that will communicate over the network. That essentially renders the solution infeasible.

Another solution is to translate the protocol to one that does not exhibit the same responses to extended latency. An example of such is the frame relay protocol used by the ICE technology. The problem with this solution is that any data or network accessed outside the NOC needs to be translated to the new protocol. This, unfortunately, eliminates the reliability aspect of the TCP and could potentially result in the delivery of invalid data.

G. SYSTEM ANALYSIS

Chapter II outlined a series of twelve criteria required for CG Coastal Homeland Defense Operations. INMARSAT is one possible solution and must be evaluated with respect to these twelve requirements.

1. Coverage

INMARSAT can provide near-global coverage and, in doing so, meets the defined requirements. The only

inaccessible areas are the extreme polar regions. These regions are not being considered in our focus for coastal homeland defense operations. INMARSAT-3 also provides the capability to increase coverage in areas of high traffic volume with its spot beam technology. These dynamically allocated spot beams can be focused on those areas most likely to experience increased communications tempo with regards to homeland defense operations. These areas will consist mainly of major US seaports.

2. Accuracy

INMARSAT is able to meet the defined requirements for accuracy. INMARSAT-B was designed with a link budget to provide a bit error rate of 10^{-6}. The system also takes advantage of forward error correction techniques such as convolutional coding to help protect against bit error transmissions. INMARSAT-B's use of adaptive predictive speech coding also increases the quality of all voice transmissions. However, the mini-M system does begin to sacrifice some of the voice quality in an effort to reduce size and power constraints of a full INMARSAT-B terminal.

3. Availability

INMARSAT systems provide marginal availability for homeland defense operations. There are two system options that need to be discussed with regards to availability: demand access or leased channel. Demand access will meet the needs of operations for most situations, but there is no way to guarantee access to the system. While INMARSAT-3 has drastically increased each satellite's total capacity, there is still a limited system capacity. When an operational unit utilizes demand access, it is competing

for channel space with every other system user in that satellite’s footprint. This could prove a problem in times of extremely high traffic volume, such as a natural disaster or national emergency.

The solution to the availability problem for INMARSAT is to purchase a leased channel. This will provide a guaranteed channel for the operational units regardless of the demand access climate. However, this solution carries with it two major problems. The first of which is cost. This will be discussed later, but may prove prohibitive. The second problem, ironically, is availability of leased channels. INMARSAT has only provided a defined number of leased channels available for purchase. Of the operational satellites, all of the available channels have already been allocated and there are no new channels for purchase. While the Department of Defense (DoD) has purchased many of these channels, the CG is not a part of the DoD and therefore CG operations are forced to compete with other DoD operations on a priority basis. This by no means guarantees constant access to a leased channel for homeland defense operations unless there is a policy change by the DoD.

There may be a partial solution to this problem. INMARSAT is planning to move another satellite to cover the Pacific Ocean region. This would provide coverage of the Pacific Coast and a portion of the East and Gulf Coasts. There are still channels available for purchase by the CG. This solution, when implemented in conjunction with a technology such as ICE, that permits the channel to be split and further allocated, may prove to be an option.

However, this will only provide a partial solution, as there will still be coastal zones left uncovered by the new satellite.

4. Cost

Cost of a fully implemented INMARSAT solution may prove the single most prohibitive factor. The cost of INMARSAT’s high-speed data (HSD) is approximately $9 per minute of usage. That equates to almost $13,000 per day of uninterrupted usage or just under $400,000 per month. While it may not be necessary to have an uninterrupted connection for a month at a time, it is still necessary to maintain a connection for several hours per day of operation. This equates to thousands of dollars every day for only 64 kbps of demand access. Currently, CG operations budget for approximately $30,000 per month for the major cutters on patrol. This provides just over 1.5 hours of dial-up connectivity per day of patrol. Also, the budgetary climate only allows for the major cutters to be allocated a budgetary line item for INMARSAT expenses, but these are not the units that will be conducting much of the coastal homeland defense operations. Currently, the CG does not have funding to support the costs of operations for the smaller vessels that will be performing much of the coastal operations.

The option of a leased channel does not provide much of a cost savings to the operation. A leased channel, if available, will cost approximately $30,000 per month, but provide 24x7 access to the HSD network. This improves the outlook slightly but still carries with it a large price tag and only provides access to a few units at a time.

The last option is to utilize a leased channel with a dynamic bandwidth allocation technology such as ICE. While this allows for both an increased data rate as well as increasing the number of units sharing the connection, it does not provide the required bandwidth when the channel is reallocated among several units. It must utilize the entire channel for one unit to achieve the required bandwidth. The system also carries with it the cost of re-capitalizing the current architecture. Each unit would have to be provided the ICEBOX as well as installing a similar unit at each gateway to the network.

5. Interoperability

INMARSAT provides an acceptable level of interoperability. It provides the capability to work as a switched network, providing point-to-point dial-up operations as well as access to its HSD. The dial-up capability allows for both ship-to-shore and shore-to-ship fully duplexed operations. This enables constant contact if a channel can be provided. It also provides the ability of the unit to access the CG’s Virtual Private Network (VPN) for access to CGDN+. The only shortfalls for interoperability are those pertaining to geosynchronous satellite latency. As discussed earlier, the extreme latency issues often effect network operations, as the network protocols were not designed for such latent operations.

6. Latency

As discussed earlier, INMARSAT operations introduce extreme latency issues into a networking scenario. The minimal one-way delay of 250 msec is enough to impede

simple voice communications. Latency becomes even more troublesome as an attempt to network over the geosynchronous satellite link is made. For network protocols, the required round-trip request/acknowledgement operations are subject to a minimum of a 500 msec delay. This delay is simply unacceptable for a network solution.

7. Reliability

INMARSAT meets the requirements for reliability. It was designed with the maritime environment in mind and has been in operation for many years. It operates on proven technology and should provide a stable and reliable communications link in the future as technologies improve and the system is updated.

8. Capacity

INMARSAT-B can provide marginal system capacity for coastal homeland defense operations. With the upgraded architecture, it can provide access to its HSD network at 64 kbps. This is below the identified minimum of 128 kbps, but does provide a manageable data rate. The overall system capacity has been increased with the use of both global and spot beam technologies in operation on all satellites. The dynamic allocation of the spot beams provides the system some means of adjusting to periods of increased traffic. However, without the purchase of a leased channel, channel assignment is still on a demand assignment basis. There is always a potential for the system to exceed its capacity of potential channels.

9. Ease of Use

INMARSAT provides an easy to use system. For point-to-point calls, it is no different than a standard

telephone. The same is true for a network connection. The service can be accessed as any other dial-up service, so there are no additional training requirements involved. Also, the CG is currently using INMARSAT systems, so there is system knowledge already present in the fleet.

10. Security

Security could prove a shortfall of the INMARSAT system. INMARSAT requires external equipment the security requirements for operation. The system can easily be implemented through a STU-III phone and achieve the required point-to-point encryption. However, STU-III is limited to a data rate of 9.6 kbps. A separate US Government (USG) certified encryption technique would be required to take full advantage of INMARSAT-B's 64 kbps capacity. As the system is a wireless technology, the potential exists for transmission interception. Even if proper encryption standards are implemented and maintained, potential shortfalls for security are the system is vulnerable to traffic analysis, diversion and man-in-the-middle attacks. This is primarily because end user encryption can use cover link signaling.

11. Maintainability

INMARSAT provides a marginal maintainability solution. The space segment is fairly maintainable as it operates in-orbit spares for all satellites. The SES terminals were designed for at-sea usage so they are fairly robust with regards to the influence of seawater and weather. The problem exists in the size of the INMARSAT-B unit. The power constraints of the system demand a fairly large antenna structure. This is a constraint as to the size of

the unit on to which it can be installed. The coastal homeland defense operations will be conducted mostly by units 87’ in length and smaller. Some of these units do not possess the deck space required for such a unit. Also associated with the INMARSAT-B system is the need for stabilization equipment. This further adds to the deck space requirements.

12. Throughput

As a single channel service, INMARSAT provides marginal throughput. The defined requirement is 128 kbps. However, INMARSAT’s current architecture can provide a capacity of only 64 kbps per channel. Additionally, this data rate is attainable only if the system is HSD-equipped. However, the actual throughput is further reduced once FEC and bit interleaving is added as overhead. More importantly, the large latency incurred by the GEO satellite system affects the actual throughput. For example, when using a transport protocol such as TCP, the actual throughput is dependent upon not only the available data rate, but also the receive window size. Using the standard window size of 8 kilobytes and an average latency of 500 msec, the maximum data rate is approximately 128 kbps. This actual throughput is further reduced by nearly 40% once each packet is formatted, encryption applied and error correction techniques implemented. This reduces the potential throughput to only approximately 70 kbps. The system is unable to achieve desired throughput without modifying transport protocols.

H. CONCLUSION

INMARSAT can provide only a partial solution. Even with its HSD network, it can provide only a portion of the required connectivity. This connectivity also comes at a cost, not only in dollars, but also in latency and the associated network issues it creates. The system also contains several security risks that may involve extensive additional equipment to mitigate. Implementing an INMARSAT network as the basis for CG connectivity, while conducting coastal homeland defense operations, may be viewed as implementing an expensive 80% solution.

IV. GLOBALSTAR

A. GENERAL OVERVIEW

The Globalstar system is a LEO satellite based mobile communications system that provides quality wireless communications for both voice and data. The system provides near-global coverage (approximately 70°S to 70°N latitudes), leaving only the polar regions without service. The system's space segment is composed of a satellite constellation of 48 operational satellites acting in a "bent pipe" capacity. The ground segment is composed of Ground Operations Control Centers (GOCC), Satellite Operations Control Centers (SOCC), the Globalstar Data Network (GDN) and Subscriber Units (SU). The key capabilities of the Globalstar system are lower usage costs, increased privacy and quality by the use of Code Division Multiple Access (CDMA) schemes, position location and path diversity. The Globalstar system was designed to complement and extend the PSTN or Public Land Mobile Network (PLMN).

1. History of Globalstar

Globalstar is a consortium of leading international telecommunications companies working together to provide high-quality, satellite-based wireless communications. The consortium was founded in 1991. The members of the consortium are listed below in table 3. Globalstar was granted a full FCC license in November of 1996. Their worldwide feeder and user link frequencies were approved by the International Telecommunications Union in November of 1995. The satellites were launched using rockets from two

manufacturers. Twenty-eight satellites were launched using the Boeing Delta II rockets and twenty-four satellites were launched using the Starsem Soyuz rockets. The constellation of 48 satellites was complete in November of 1999 and the system was fully operational in the fall of 2000.

Loral Space & Communications Ltd. (www.loral.com)
One of the world's leading satellite communications companies

QUALCOMM, Inc. (www.qualcomm.com)
A leader in CDMA technology

Alcatel (www.alcatel.com)
The world's largest manufacturer of telecommunications equipment

Alenia Aerospazio (www.alespazio.it)
A Finmeccanica company, the major Italian space industry provider

China Telecom (www.cthk.com)
A leading Chinese telecommunications company

DACOM (www.dacom.co.kr)
A leading South Korean telecommunications company, which pioneer Korea's data telecommunications industry during the last two decades.

DaimlerChrysler Aerospace (www.eads-nv.com)
A world leader in aerospace, defense technology and propulsion systems

Elsacom (www.elsacom.com)
Elsacom is a Finmeccanica company specializing in the provision of fixed and mobile satellite telecommunication services that operate on the international market.

France Telecom (www.francetelecom.fr)
The world's fourth largest telecommunications operator, with 30 million subscribers and operations in 31 countries

Hyundai (www.hei.co.kr)
A US $70 billion company and South Korea's largest conglomerate

Space Systems/Loral (www.ssloral.com)
One of the world's most experienced manufacturers of commercial communications satellites

Vodafone (www.vodafone.com)
In July 1999, Vodafone of the United Kingdom merged with another Globalstar partner, AirTouch, to form the world's largest provider of mobile telecommunications services

Figure 10. Globalstar Consortium [From Ref. 20]

2. Land Segment

Globalstar was designed to be a wholesaler of wireless communication services. The consortium provides the satellite constellation and the technology to use and maintain the system, but other entities provide the actual service to the users. Usually, this service is provided by a single country or by several countries located near each other. To become a service provider, the country needs to purchase, install and operate a gateway. A gateway is the link between the Globalstar satellite constellation and existing terrestrial communication systems. Keeping in mind that Globalstar was designed to complement and extend a current PSTN or PMLN not replace it; a Globalstar gateway can connect to either an existing PSTN or a cellular network. The gateway is compatible with either the European cellular standard of the Global System for Mobile Communications, Groupe System Mobile (GSM) or the US standard of Advanced Mobile Phone Service (AMPS) of a PMLN. The gateways integrate to the PSTN utilizing a standard T1/E1 interface. An example of this is below in figure 10.

Figure 11. User to destination connection [From Ref. 21]

Each gateway is composed of three or four dish antennas, a switching station and remote operating controls. The typical gateway can cost between $3 million and $6 million depending upon the number of subscribers to be supported by the gateway. These cost estimates also assume the gateway is collocated with a switch to the appropriate terrestrial or cellular network. [Ref. 20]

Each segment of a gateway is designed in a modular manner. This allows for up to 16 separate service providers to operate from a single gateway. Not only does this allow for synchronized growth to meet market demand, but it also allows for several service provides to share the cost to obtain and maintain an operational gateway.

The Globalstar system is designed as a bent-pipe system. This means that the satellites do not conduct any signal processing other than to amplify and repeat the signal to a ground station or gateway. As Globalstar works to complement and extend PSTN and PMLN systems, all the required switching is completed by the gateway. By designing the system as such, the majority of the systems technology is located at the gateways. This provides for easy maintenance and updates. The design of the gateways also provides several other features that allow Globalstar to remain competitive in the market. [Ref. 11, p.529]

- Standard ET1/T1 interfaces to PSTN/PMLN
- Programmable signal interfaces to connect to local infrastructure
- Up to 16 service providers can share the cost of a gateway
- Firewall services to ensure security
- Seamless services for satellite, GSM and AMPS

- Cellular GSM and AMPS features at each site
- Unmanned operations with remote monitoring and operations
- Encryption for voice and signal security [Ref. 20]

Several distinct control segments are contained within each gateway. These control segments include space control segment, ground control segment and the user segment.

a. Ground Operations Control Centers

The Ground Operations Control Centers (GOCC) are responsible for planning and controlling the use of satellites by gateway terminals. They are also responsible for coordinating with the Satellite Operation Control Center (SOCC). GOCC's plan the communications schedules for the gateways and control the allocation of satellite resources to each gateway. The GOCC is responsible for monitoring and maintaining the status of the entire ground segment in addition to assigning the satellite's resources to the gateways. [Ref. 20]

b. Satellite Operations Control Center

The Satellite Operations Control Center (SOCC) manages the Globalstar satellite constellation. The SOCC tracks satellites, controls their orbits, and provides telemetry and command (T&C) services for the constellation. Globalstar satellites continuously transmit spacecraft telemetry data that provides on-board health and status reports for the satellites. The SOCC also oversees satellite launch and deployment activities. The SOCC and GOCC facilities remain in constant contact through the Globalstar Data Network (GDN). GDN is the network connection that the provides wide-area communications

between the Gateways, the GOCC’s, and the SOCC’s necessary to maintain the system. [Ref. 20]

c. Subscriber Units

Globalstar’s subscriber units (SU) are divided into three separate classes. These classes are fixed, mobile, and personal. The fixed SU’s are telephone-booth-type units. These SU’s are commonly found in remote, hard to reach areas of a country that do not benefit from a fixed PSTN or PLMN system. This can be much more cost effective than running wire or fiber to every remote part of the planet. The mobile SU’s can be mounted in a vehicle. This can often provide an alternate means of power supply, allowing the handset to extend the life of the battery and provide hands-free operation. The third and final type of SU is the personal SU. These units utilize an omni-directional antenna and provide worldwide digital service similar to a cellular phone. There are two types of personal SU’s, dual-mode and tri-mode handsets. The dual-mode supports both Globalstar and GSM cellular standards. The tri-mode unit supports Globalstar, AMPS, and IS-95 (a CDMA cellular standard). [Ref. 20] Figure 11 demonstrates the interaction between the ground segments and the PSTN/PLMN.

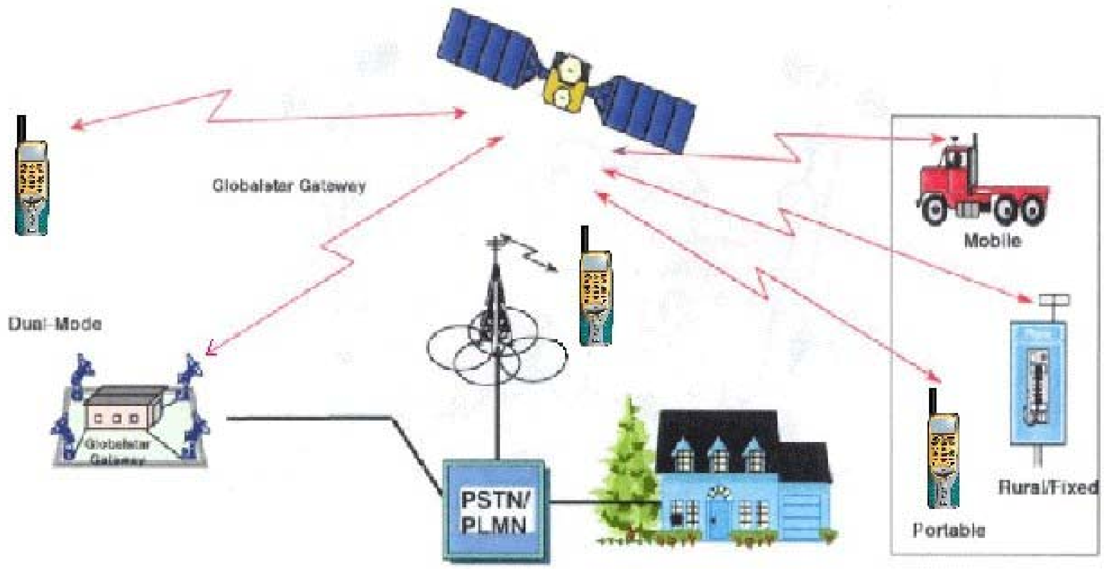

Figure 12. Globalstar system architecture [From Ref. 21]

3. Space Segment

The space segment of the Globalstar system consists of 48 operational satellites and 4 in-orbit spares. The operational satellites are maintained in 8 eight orbital planes, with 6 satellites in each plane and at a height of 1414 km, which is below the Van Allen Belt. The orbital period for each is 114 minutes. The constellation concentrates satellite coverage over the more temperate and highly populated areas of the earth. It is designed to provide 100% coverage by at least 2 satellites from 70°S to 70°N latitude. [Ref. 22, p.4] Figure 12 demonstrates the world coverage of Globalstar.

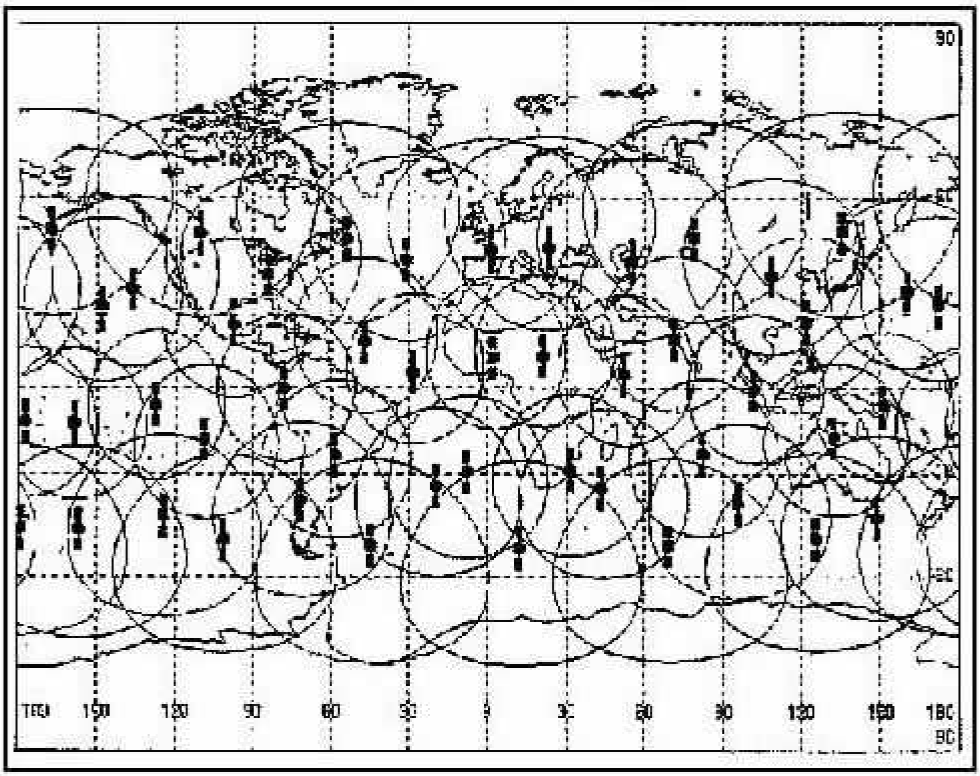

Figure 13. Globalstar coverage map [From Ref. 18]

The Globalstar satellite was designed to be a simple and relatively low cost satellite. Cost of the satellite becomes an issue when launching a LEO constellation, as it requires approximately 50 operational satellites vice only 3 or 4 for a GEO constellation. The Globalstar satellites were designed to operate in a “bent pipe” system. This means that the satellites themselves contain no onboard processing capabilities. The satellite simply connects the user and a gateway.

The satellites are axis stabilized and utilize GPS to track their orbital location. Each satellite contains 5 thrusters used for orbit control, station keeping and attitude control. The electrical power is provided by two solar arrays and associated batteries capable of

maintaining operational power during solar eclipses. Communications are provided by phased array antennas and utilize C-, L- and S-band frequencies. Each satellite’s footprint is produced by a pattern of 16 spot beams that can cover an area of several thousand kilometers in diameter. The current generation of satellites has a design life of 7.5 years. [Ref. 21]

a. Power

As with any space segment, power consumption is a concern. Globalstar is a LEO system and benefits from many of the reduced power requirements when compared to a GEO system. Because the satellite is much closer to the earth’s surface and the targeted users and gateways, the system allows for smaller antenna gain requirements and EIRP values than a GEO system. This allows for smaller, less sophisticated antennas and lower power requirements.

Each satellite has a total power consumption of between 600 W during quiet state to over 2000 W at times of peak system usage. To meet these requirements, each satellite is powered by two solar arrays. These arrays automatically track the sun as the satellite is in orbit. The arrays can provide between approximately 1100 W and 1900 W of electrical power based upon their age. The two arrays also work to charge the satellites nickel-hydrogen battery system. This battery system is capable of providing system power to the satellite during a solar eclipse, which can last as long as 33 minutes. The battery system also provides surplus power to they satellite in times of increased usage. [Ref. 23, pp.936-942]

b. Telemetry and Command

The Telemetry and Command (T&C) subsystem is the means by which the ground segment monitors and maintains the space segment. Telemetry is the critical information that the satellite reports to a ground station concerning the status and health of the satellite and its subsystems. The ground station interprets this information and issues command messages. These command messages can alter the orbit of the satellite, adjust control functions, modify power controls or query subsystems for updated information.

The T&C subsystem operates using two C-band communication links. Each satellite is assigned one of 12 separate channels for telemetry transmission. These 12 channels are 10 kHz-wide channels at about 6,877 MHz. The command information is sent via a channel centered at approximately 5,091 MHz. The channel is 160 kHz wide and achieves a data rate of approximately 1 kbps. The entire T&C subsystem utilizes single-beam C-band antennas for the transmission of T&C information. All transmissions are encrypted to prevent unauthorized access to the satellites T&C subsystem. [Ref. 23, p.940]

c. Communications Payload

The Globalstar's satellite communications payload consists of L- and S-band phased-array antennas, C-band horn antennas, power amplifiers and frequency converters. As mentioned, Globalstar is a "bent-pipe" system. Also, there is no inter-satellite link in the Globalstar system. This further reduces the required communications payload. The satellite communicates only with users and gateways. When a satellite receives a signal, it simply amplifies the

signal, translates the signal to the appropriate frequency and transmits the signal over the appropriate channel. The simple system design and limited requirements work to limit the cost of the satellite and ease maintenance requirements. [Ref 24, p.185]

Globalstar utilizes L-band (1610-1626.5 MHz) frequencies for user-to-satellite communications. The communications payload amplifies the signal and translates it to a C-band channel (6875-7055 MHz) and relays it to the gateway for further connection to a PSTN/PLMN or another SU. Globalstar terms this the reverse link. The forward link is from the gateway to the user. In this link, the gateway transmits the signal to the satellite in the C-band (5091-5250 MHz). The satellite then amplifies the signal and translates it to an S-band frequency (2483.5-2500 MHz) before transmitting to the user. The allocated bandwidth between the user and the satellite is divided into thirteen 1.25 MHz channels for each link. [Ref. 20]

Globalstar uses a sophisticated phased array antenna for both the L- and S-band links. The antenna divides the coverage for the satellite into 16 beams that collectively fill the satellite's coverage footprint. Each antenna provides coverage of the earth's surface in a circle with a diameter of 5760 km. While both the L- and S-band antennas provide equal coverage, the 16 separate beams of each are arranged in a different manner. The beams for the S-band link are arranged in a honeycomb pattern with one beam in the center surrounded by a circle of six beams, which are surrounded by a circle of nine beams. The L-band link is composed of one beam in the

center surrounded by a circle of 15 beams. [Ref. 20] Figure 13 illustrates the multi-beam scheme.

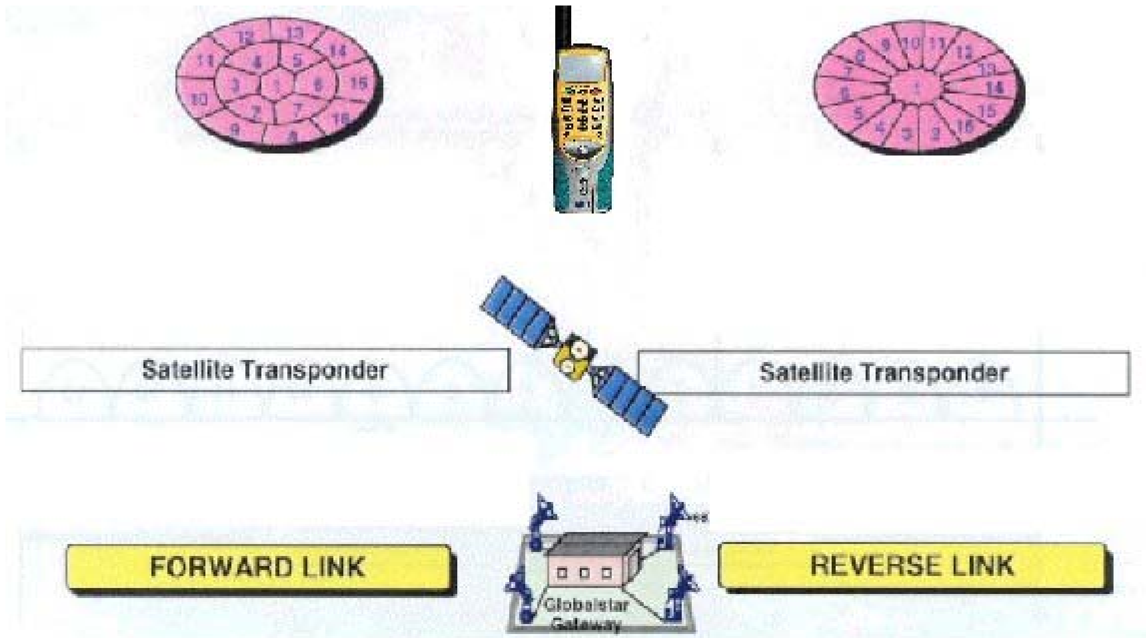

Figure 14. Globalstar multi-beam scheme [From Ref. 21]

The multi-beam antenna scheme serves three purposes. First, the individual beams of each link can provide a higher gain than a single antenna beam serving the entire area. Secondly, the entire L- and S- frequency band allocated is used in each of the 16 beams. The frequency spectrum from each of the beams is combined using an FDMA scheme into a single broad spectrum. This increases the total system capacity. [Ref. 21] Lastly, the individual beams allow the user to take advantage of path diversity. Path diversity contributes an increase to both system efficiency and quality of service. This will be discussed later in the chapter.

B. ORBIT AND CONSTELLATION

As mentioned above, the Globalstar system employs a satellite constellation of 48 operational satellites and 4 in-orbit spares deployed in a LEO orbital pattern. The satellites maintain a nearly circular orbit at the height of 1,414 km (approximately 764 nm). The constellation is divided in to 6 orbital planes with 8 satellites per plane. Each plane is spaced 60 degrees apart. Figure 14 demonstrates the orbital planes of the constellation.

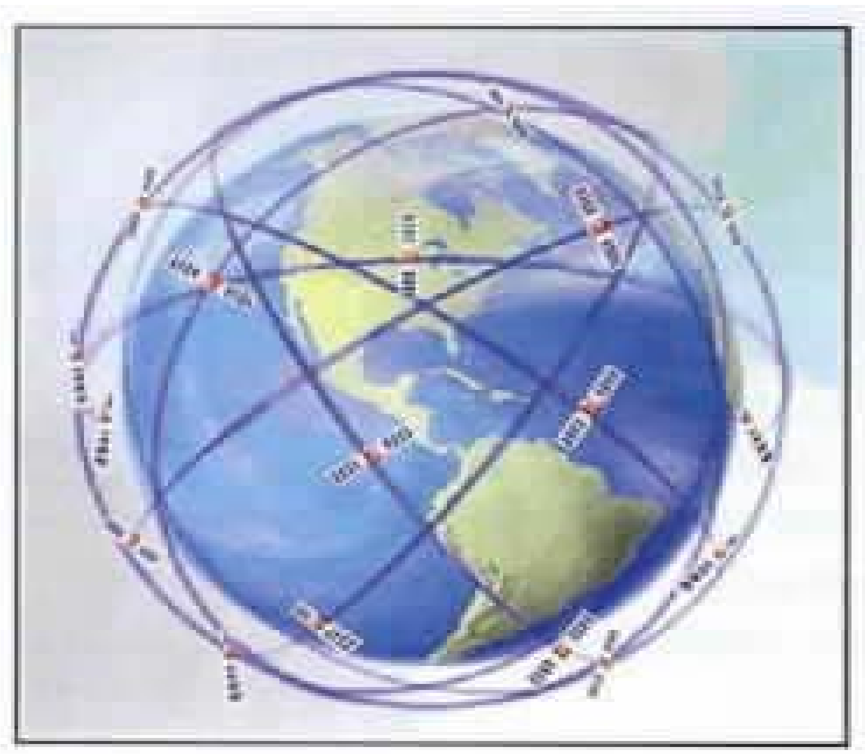

Figure 15. Globalstar orbital planes [From Ref. 21]

1. Inclination of Orbit

Each satellite is inclined at an angle of 52 degrees. Figure 15 provides a representation of the relative signal based upon the inclination of the orbital plane. With

Globalstar operating at an inclination of 52 degrees, it has relative signal strength of approximately –11 dB when compared with other LEO constellations.

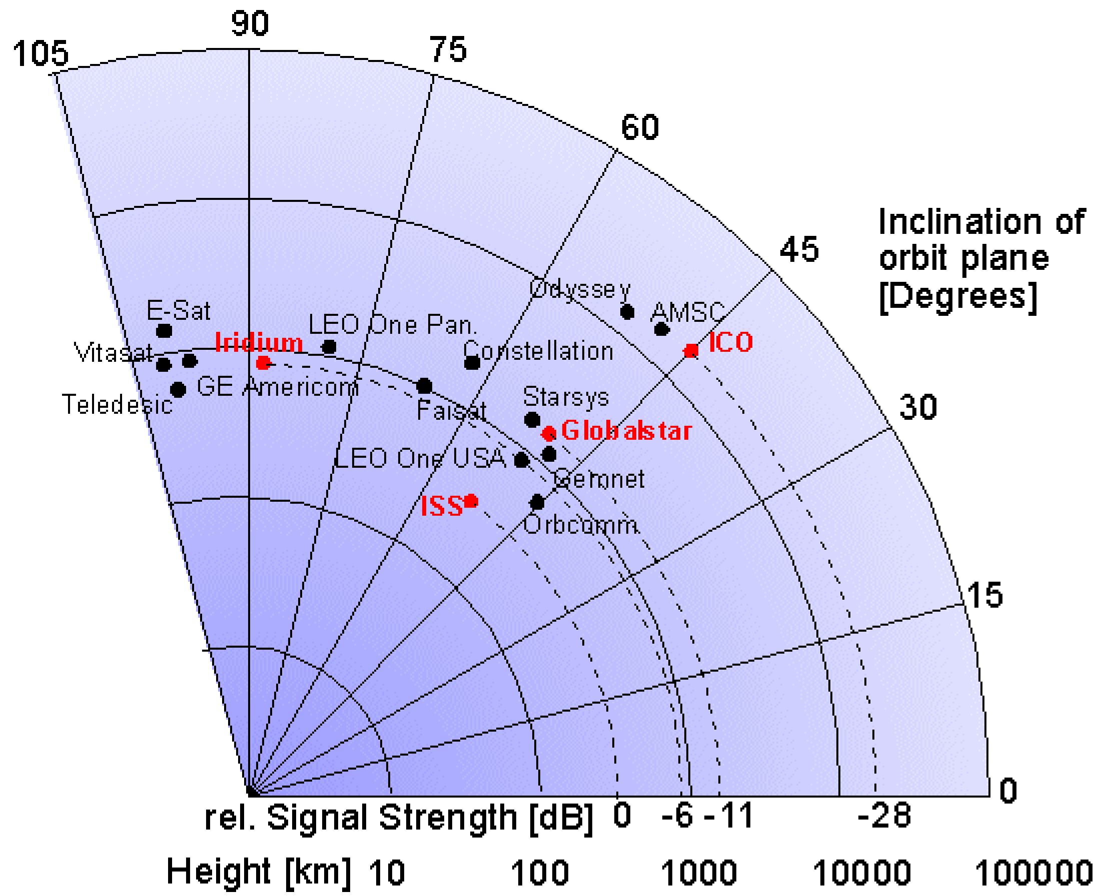

Figure 16. Signal strength by orbital plane [From Ref. 21]

2. LEO Impacts

Globalstar operating as a LEO constellation has several impacts on the communications system. While operating at the height of 1,414 km, each satellite has a high speed relative to the rotation of the earth. A Globalstar satellite has an orbital period of only approximately 114 minutes. This equates to an orbital velocity of approximately 7.15 km/sec. To put these

numbers into perspective, each satellite will only be in view of a user on the earth’s surface for approximately 14 minutes. This is a relatively short time when compared to a GEO satellite that is in constant view from a given point on the earth’s surface.

a. Doppler Effect

The rapid rate of relative motion each satellite exhibits with respect to the user on the earth’s surface results in a significant Doppler shift in the transmitted signals. The Doppler shift is an apparent shift in a frequency due to rapid relative motion. The Globalstar system can experience Doppler shifts as high as +/- 50 kHz on the forward link and +/- 35 kHz for the reverse link. [Ref. 20]

b. Hand-offs

The Globalstar system has to provide a means to seamlessly hand-off a call from one satellite to another. This is a result of each satellite only being in view of the user for approximately 14 minutes. While each satellite is only visible for such a short period of time, it is common for a call to have to be switched from one satellite to another. This hand-off has to occur without the user losing connection if the system is to be effective. Further compounding the problem is Globalstar’s use of multiple beams for each satellite. The multiple beam design results in a user switching between beams every two to four minutes. This hand-off must also appear transparent to the user. Globalstar has addressed these issues by employing a modified version of Qualcomm’s terrestrial CDMA technology. [Ref. 20] Figure 16

demonstrates the two possible hand-off procedures as the user moves through the satellite’s footprint.

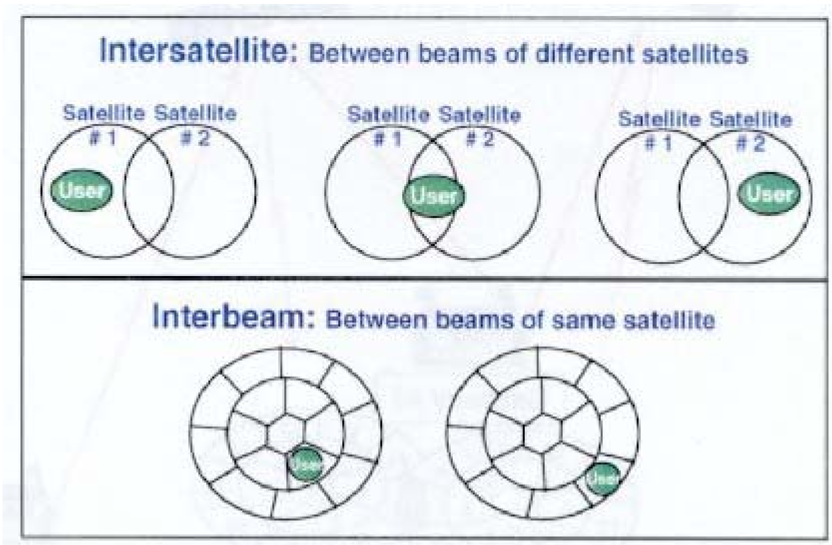

Figure 17. Globalstar handoffs [From Ref. 21]

c. Path Diversity

Another attribute of the LEO constellation is the ability for Globalstar to employ path diversity. Path diversity increases both system efficiency and quality of service. The concept of path diversity is that the user can take advantage of the signals provided by more than one satellite, or more than one beam from a single satellite. When the user receives a signal from more the one satellite or more than one beam from a single satellite, the Globalstar system combines the signals. This produces a signal of superior strength than a signal using only one link. This equates to several links (or paths) carrying the same signal being combined to produce one signal of very high quality for the user. [Ref. 20]

Path diversity also reduces the total power required for the system. Since the path diversity technique combines the signal from several links to provide one high quality signal, each link can operate at a relatively low E_b/N_o. [Ref. 20]

Path diversity also provides increased coverage for the user. For example, if a building or another large object blocks the direct path to a single satellite, the user will still be able to receive a signal if another beam or satellite is in view. The path diversity allows these other signals to be combined to form a single high quality signal. This is not true of systems, such as a GEO system, that cannot employ path diversity. For such systems, if the view of the satellite is blocked, so is the signal. [Ref. 20]

d. Power Requirements

Another advantage the LEO constellation provides the Globalstar system is that of reduced system power requirements. The LEO system has much shorter distances between the user and the satellite than a GEO constellation. This shorter distance translates to lower propagation path losses for the link budget. These lower path losses allow the Globalstar system to be designed with lower antenna gain requirements and EIRP values. These advantages not only reduce the overall system power requirements but also allow the SU to use small hand-held units with omni-directional antennas. This is in contrast to the GEO requirements for stabilized and directional antennas. Cumulatively, these advantages reduce the user's cost to deploy the Globalstar system. [Ref. 20]

e. Latency

Perhaps the most significant advantage a LEO system provides is very small system latency. As the satellite constellation is only deployed at 1,414 km, the time involved for a signal to travel from a user, to the satellite and then to the gateway is minimal. The latency induced by the Globalstar system is often less than that of a typical WAN deployed in the US. This reduced latency greatly improves the ability to deploy a wireless network utilizing the Globalstar system. Another advantage is that latency will be almost imperceptible in voice transmissions. This is in contrast to the noticeable delay involved with GEO voice transmissions. [Ref. 20]

C. OPERATIONAL CAPABILITIES

The Globalstar system was designed to provide a number of capabilities to the user. These capabilities include several data and voice services. These voice services consist of closed user group links, mobile to mobile links and voice messaging. Aside from the voice services, the system also provides a geographical locating function and a variety of data services ranging in data rate from 2.4 kbps to 9.6 kbps depending upon the application. Regardless of the service being used, each transmission follows a similar call procedure.

1. Call Procedure

Before any Globalstar service can be activated, the user must first establish a communications link with a Globalstar host gateway. After a brief synchronization sequence, the gateway contacts the Globalstar Business Office (GBO) and conducts a verification of the user's

billing information. The gateway then queries the SU for location information. The gateway then transmits information concerning CDMA codes, channel assignment and any required synchronization data. Once the SU receives the information and the link is synchronized, the unit can begin to transmit.

A similar procedure is followed if the call is initiated from a PSTN/PLMN site. The PSTN/PLMN directs the call to the local gateway. The gateway then determines if the user is within the same coverage area. If the user is within the coverage area the gateway makes a similar transmission with CDMA code, channel and synchronization information to the SU. If the user is not within the coverage area of the regional gateway, the call is forwarded to the user’s regional gateway and the procedure above is followed. [Ref. 20] Figure 17 illustrates the call procedure.

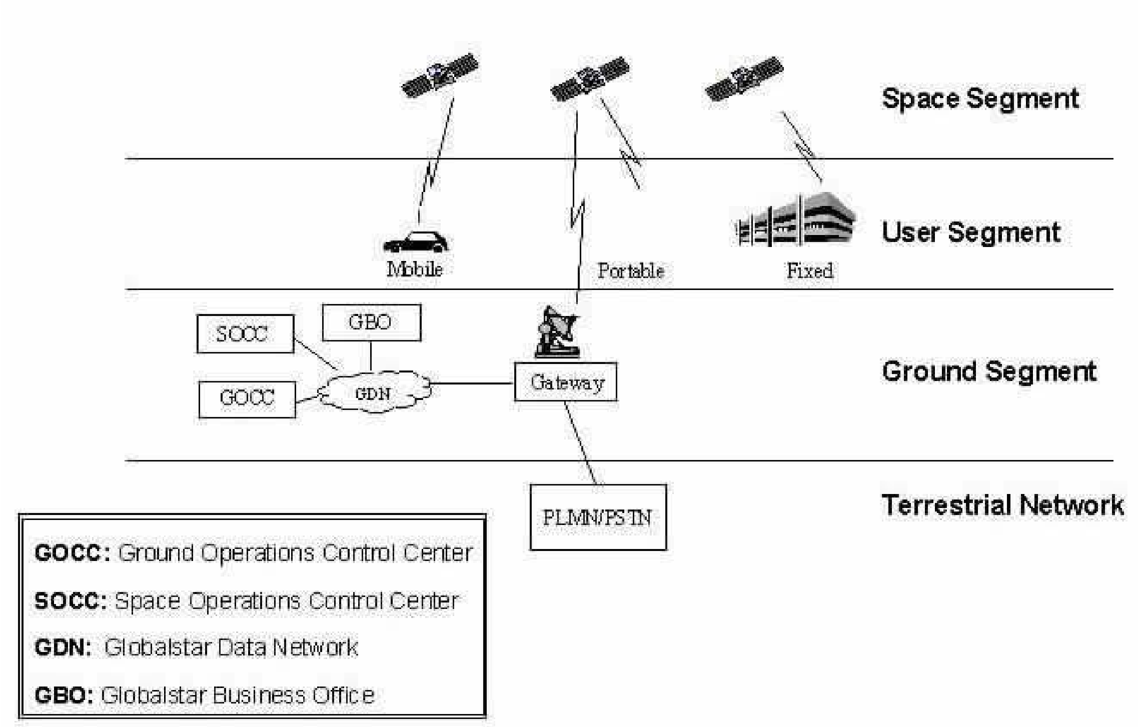

Figure 18. Globalstar call procedure [From Ref. 21]

2. Position Location Services

Globalstar has the capability to provide the unique service of position location to its users. Globalstar terms this position location capability as radio-determination satellite service (RDSS). [Ref. 20]

The RDSS is based upon the QUALCOMM's technique called QUALCOMM's automatic satellite position reporting (QASPR). The technique utilizes the range and Doppler information from two satellites to obtain the positional data. When utilizing two satellites separated by 22 degrees, the position can by measured to within 300 meters. The technique was designed to utilize the timing backbone of the Globalstar service to avoid additional bandwidth requirements for the service. The technique uses a method known as tri-lateration to calculate the position. Tri-

lateration utilizes three distinct points to determine a position. The three points used for the RDSS are the positions of two satellites and one fixed point defined as the center of the earth. This last point is the origin in the Earth Centered Fixed (ECF) coordinate system. [Ref. 12] The range data for these three points is generated and utilized to calculate the position of the SU.

The service is available to users at three separate levels of operation. For the first level of service is the passive level of service. The SU computes the position and makes it available only to the user. This level of service is similar to carrying a personal GPS unit. It has several potential applications that include boating. At the second level of service, the SU requests the gateway to calculate the SU's position. This request is in the form of two-messaging between the SU and the gateway. Once the position is calculated, it can be distributed to both the user and other entities as determined by the user. This level of service is applicable to any scenario when the user wishes to mark and broadcast a position such as a distress situation. The final level of service involves the gateway calculating the SU's position automatically. This level of service is very applicable in a fleet management and tracking scenario. [Ref. 20]

3. Voice Services

One of the primary services provided by the Globalstar system is voice communications. The system provides voice services at the rates 1.2, 2.4, 4.8 and 9.6 kbps. The actual data transmission rates are slightly slower due to the use of overhead bits in the transmission. All voice

services utilize Qualcomm's CDMA vocoder. The vocoder takes advantage of the fact that in a two-way voice conversation the average duty cycle of each voice is typically only 35% to 40%. The Globalstar system takes advantage of this fact and reduces the transmission data rate when there is less speech activity. This allows for a reduction in transmitter power and a corresponding reduction in interference to others. By reducing the interference to others, you can increase both capacity and energy efficiency. TDMA and FDMA systems cannot produce these efficiencies as each signal operates in a separate time slot or frequency channel. The Qualcomm vocoder uses a 20 msec frame interval to produce the four different data rates. The data rate can vary every 20 msec frame in response to voice activity. When there is no voice activity, the rate drops to its lowest level of 1.2 kbps. This drop in data rate signals the system to reduce transmission power. These efficiencies, when coupled with easy access to the PSTN/PLMN, allow the Globalstar system to be a viable option for near-global voice services. [Ref. 22, p.14]

4. Data Services

Globalstar systems were designed to deliver data services to the users. The system can use a satellite modem that is attached to the SU. Once a link is completed with a regional gateway, the system allows for data transfer at speeds up to 9.6 kbps. The system is a packet switched data service and utilizes IP protocols. The average throughput is 7.4 kbps per channel due to overhead bits and TCP/IP protocols. The data services support Virtual Private Network (VPN) tunneling protocols to

provide a secure network connection. The data services are also compatible with Windows 95/98/2000/XP dial-up networking. [Ref. 20]

The Globalstar data service offers several advantages over other satellite communications systems. The first advantage is that the system was designed for connection to PSTN/PMLN networks. This provides easy access to terrestrial networks for dial-up network connections. The second advantage is that of being a GEO system. With the reduced latency of the GEO system, the Globalstar data services do not suffer the same TCP/IP difficulties incurred by the large latency associated with GEO systems. The latency incurred by a LEO system is no different than that incurred by a terrestrial WAN (on the order of tens of msec). [Ref. 20]

5. Path Diversity

As mentioned earlier, Globalstar provides path diversity for the user. The SU takes advantage of the fact that several satellites will be in view of the user at one time. The SU utilizes a rake receiver to link to more than one of these satellites at one time. The SU can then transmit and receive by way of the link with the best signal quality or combine all available signals to produce a better quality signal. This allows the user to maintain a communications link if the view of a single satellite is blocked by a structure or even storm cell activity. This diversity scheme allows for a high degree of circuit availability and allows the SU to operate at a lower power level. [Ref. 25] Figure 18 demonstrates the concept of path diversity.

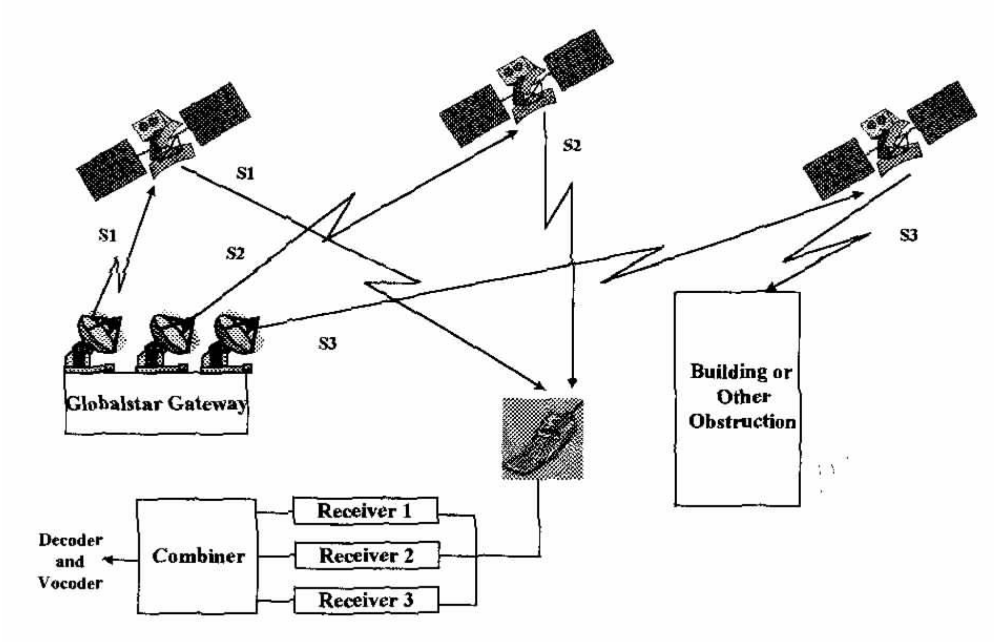

Figure 19. Globalstar path diversity [From Ref. 25]

6. Code Division Multiple Access

The Globalstar system employs Qualcomm's Code Division Multiple Access (CDMA) scheme to address the system's multiple access issues. Multiple access is the ability to allow many users to share a common bandwidth. CDMA is one of several common techniques used to address multiple access. Aside from CDMA, FDMA and TDMA are the other techniques used in many communication systems. CDMA is a spread spectrum technology. This means that each user's data is transmitted across the entire frequency rather than limiting it to a specific time slot or frequency band as with TDMA and FDMA respectively. CDMA operates by assigning each user a pseudo-noise (PN) code. The PN is a long, binary sequence that appears random. While the PN code appears random, it is generated using a specific algorithm that provides orthogonal codes. The PN code is

then used to modulate the data to be transmitted. [Ref. 20] An example of the system is illustrated in figure 19.

CDMA allows several users data to be transmitted at the same time over the total bandwidth. Each user's data is essentially stacked on top of the other data to be transmitted. As each user's data is modulated with a PN code that orthogonal and unique to all other codes, the code isolates each user's data in the code dimension. This is similar to different frequencies or different time-slots isolating each user in other multiple access schemes. CDMA also allows for better spectral efficiency and increases the ability to reuse frequencies. CDMA techniques also result in a lower average transmission power requirement as each signal is spread across the entire bandwidth. [Ref. 20]

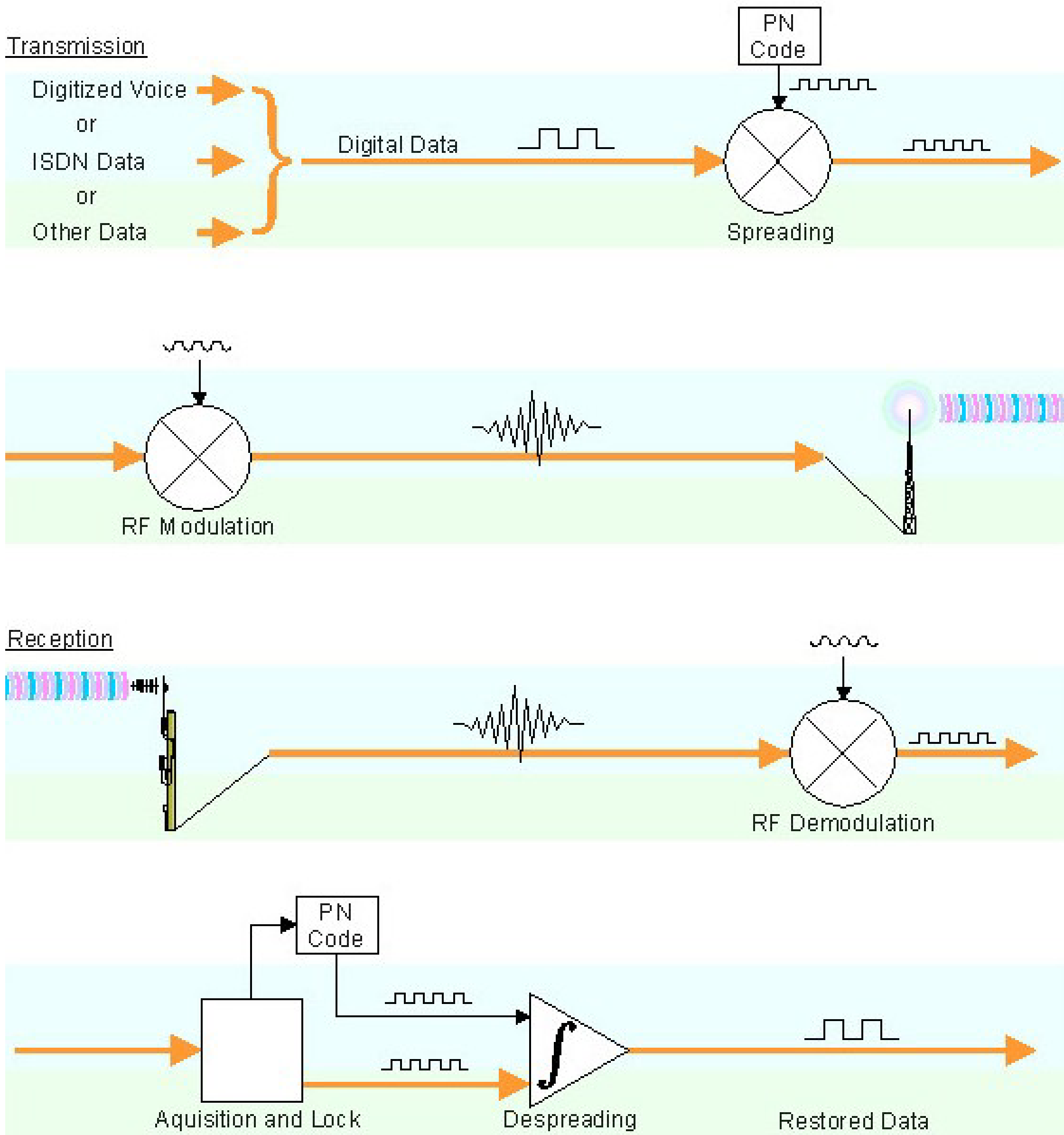

Figure 20. CDMA Modulation Scheme [From Ref. 26]

D. SYSTEM ANALYSIS

Chapter II outlined a series of twelve requirements for CG Coastal Homeland Defense Operations. In order for the Globalstar system to be considered as a viable option, it must meet the minimum of these twelve requirements.

1. Coverage

Globalstar can provide near global coverage and in doing so meets the defined requirements. The polar regions, are the only areas not covered by the Globalstar system. The polar regions are not being addressed as part of costal homeland defense. The system also provides for increased circuit availability by making use of the path diversity attributes of a LEO system. This will equate to better coverage, even when operating in areas potentially blocked by large structures such as a shore-side environment.

2. Accuracy

Globalstar is able to meet the defined requirements for accuracy. Through the use of CDMA technology, the system is able to achieve an increase in bandwidth efficiency and therefore take advantage of forward error correction techniques. This helps to protect against bit error transmissions. CDMA technology and the use of a LEO constellation also allow for a lower transmission power. This reduction in transmission power provides a substantial reduction in interference to others using the system.

3. Availability

The Globalstar system provides adequate availability for homeland defense operations. One advantage the Globalstar system can provide is that of compatibility with established cellular networks. The standard Globalstar SU provides the capability for the user to access a local cellular network if available. This provides the user with the option of using the cellular network vice the satellite

system for some communications. The system is available for use with AMPS and GSM cellular system.

One potential shortcoming of the Globalstar availability is that the system does carry with it a user capacity for each satellite. Each satellite is only capable of handling approximately 1000 users. This upper limit may prove constraining when dealing with times of extreme use such as generated by a national emergency. However, these operating limits are offset by the system's ability to manage its capability by such techniques as path diversity.

4. Cost

Cost is perhaps one of the largest benefits of the Globalstar system. Its costs are much lower than other satellite communication solutions for both usage and equipment. The cost per minute of usage is approximately .80 cents/min per channel. This is in comparison to the nearly $9 per minute per channel for INMARSAT. The other cost savings that Globalstar provides is that of the actual subscriber unit. The LEO constellation works to reduce the required power of the system. This power reduction equates to units that can utilize an omni-directional antenna, vice having to equip each unit with a stabilized, directional antenna. The entire system can be accessed with a SU that is the approximate size of a cellular telephone.

5. Interoperability

Globalstar provides an acceptable level of interoperability. It provides the capability to work as a switched network, providing point-to-point dial-up operations as well as access to PSTN/PLMNs. As mentioned

above, the system also provides easy access to a local cellular network when available. The dial-up capability allows for both ship-to-shore and shore-to-ship fully duplexed operations. It also provides the ability of the unit to access the CG's Virtual Private Network (VPN) for access to CGDN+.

6. Latency

As discussed earlier, Globalstar eliminates the latency issues normally associated with GEO communication systems. This reduction of latency, to that of a typical terrestrial network, allows common networking protocols such as TCP/IP to be employed. There is also not distinguishable delay in any voice conversations. This is also in contrast to a GEO service provider.

7. Reliability

Globalstar meets the requirements for reliability. It has solutions designed with the maritime environment in mind and has proven reliable through several years of operations. It operates on proven technology and should provide a stable and reliable communications link in the future as technologies improve and the system is updated.

8. Capacity

Globalstar provides less than marginal system capacity for coastal homeland defense operations. The current architecture can only provide services for approximately 1000 users per satellite. However, the overall system capacity has been increased with the use of CDMA technology and path diversity. There is always a potential of the system exceeding its capacity of potential users during

times of extreme usage such as a national or regional emergency.

9. Ease of Use

Globalstar provides an easy to use system. For point-to-point calls, it is no different than a standard cellular telephone. The same is true for a network connection. The service can be accessed as any other dial-up service, so there are no additional training requirements involved. The proliferation of cellular communications would ease the transition of the Coast Guard to a Globalstar solution.

10. Security

Globalstar meets the security requirements for operation. While the system is a wireless technology, the potential exists for transmission interception. This is offset by the use of both CDMA technologies and Globalstar’s system encryption. CDMA is a spread spectrum transmission technology that makes it difficult to intercept or monitor transmissions. Globalstar also provides an additional system encryption add-on. This add-on features a 128-bit encryption key. The device can alternatively be programmed with Advanced Encryption Standard (AES) or Data Encryption Standard (DES) digital cryptographic algorithms. This provides end-to-end security for both satellite voice and data services. [Ref. 18] Globalstar’s use of a bent-pipe architecture minimizes the risk of signal manipulation and traffic analysis. This architecture also allows for user installed link encryption.

11. Maintainability

Globalstar provides a marginal maintainability solution. The space segment is fairly maintainable as it operates in-orbit spares for all satellites. The SU terminals were designed to reduce the power and therefore the size of the unit. This eliminates the need to maintain a stabilized, directional antenna. The coastal homeland defense operations will be conducted mostly by units 87’ in length and smaller. The Globalstar system’s reduced size provides an advantage to units with limited deck space. The only potential downfall of the size reduction is the potential for the SU to be lost overboard during at-sea boardings.

12. Throughput

As a single channel service, Globalstar provides only marginal throughput. The defined requirement is 128 kbps. Globalstar’s current architecture can provide only 9.6 kbps per channel. This is further reduced to only approximately 7.4 kbps per channel once FEC and bit interleaving is added to the overhead.

The potential exists to overcome Globalstar’s limited throughput. Qualcomm, Inc. is currently developing solutions to increase data rates to 144 kbps with actual throughput of approximately 128 kbps. These solutions essentially join 16 separate data channels. The separate channels are joined at the transceiver and are transmitted over a single carrier using unique CDMA technologies. While these solutions meet the requirements of 128 kbps, there are some potential problems implementing them. Currently, the technology is only experimental. Also,

Qualcomm, Inc. has not yet incorporated this technology in any maritime solutions; it is only being researched for aviation and land mobile applications. In order for the CG to take advantage of this type of technology, they would have to pursue the design, testing and initial implementation of such a system. This could prove quite expensive, but very beneficial in the long run. As Qualcomm, Inc. has not yet deployed the technology; there is no pricing data available as of the time of this research.

E. CONCLUSION

Globalstar can provide only a partial solution. While it provides some advantages over other systems, it still falls well short of the data rates required for coastal homeland defense operations. To overcome the low data rates, a solution to multiplex several channels must be implemented. This may cause problems, as the solution will have to be proprietary to the CG. One benefit the Globalstar system provides is increased security. The system is able to provide both link and full system encryption. This is an advantage that other systems do not provide. The system addresses several items of concern when compared with a GEO system, but it is unable to fully meet the connectivity requirements of a full solution.

V. BUYING INTO NAVY SATCOM ARCHITECTURE

A. NAVY SATCOM

In 1991, a decision was made, based on the lessons learned from Desert Storm, to equip all Navy ships with INMARSAT. It was obvious to DoD that additional satellite connectivity was needed for the following: noncombatant evacuation operations (NEO), augmentation of military assets, administration, logistics, mission support traffic, interoperability with national and international merchant shipping, coordination of search and rescue operations, increased ship to shore direct dial telephone access to support Combined Joint Task Force (CJTF) operations. [Ref. 27]

Lessons learned from Desert Storm documented the necessity of an alternate commercial communications service. This service would be needed for logistics and operational support requirements to reduce the saturation of communications on the military tactical satellites. The Assistant Secretary of Defense (Command, Control, Communications, and Intelligence) (ASD[C3I]) in a letter of 8 Nov 1993 directed the use of commercial satellite (COMMERSAT) to augment current and future MILSATCOM systems. This would relieve the congestion on military tactical satellite communications systems. In addition, it would also enhance the overall Navy tactical communications capacity and reduce the competition with tactical data on the limited tactical satellite assets.

In an effort to support these communications endeavors, the Department of Defense organized an agency to

help procure and ensure compatibility of DoD communications systems. The Defense Information Systems Agency (DISA) is the U.S. Defense Department organization tasked with these duties. In addition they are also responsible for information assurance, preserving radio spectrum, ensuring interoperability and establishing secure wireless links for all military services. Since the 1997 mandate, this agency has been the DoD-designated manager of the Defense Communications System (DCS). DISA designs, engineers, and develops the DCS to satisfy validated requirements. DISA has overall responsibility for planning, developing, and supporting C4I systems that serve the needs of the National Command Authority (NCA). DISA is subject to the direction, authority, and control of the (ASD[C3I]), but is responsible to the Chairman of the Joint Chiefs of Staff for operational matters, as well as requirements associated with the joint planning process. [Ref. 28, p.11]

In 1998-99, seen as an unnecessary middleman, many customers began to take advantage of a loophole in DISA policy to circumvent the system. Through that narrow window of opportunity, managers of the Navy/Marine Corps Intranet (NMCI) demonstrated that commercial service providers could step in and take over the organization’s mission. DISA, realizing its failure in customer service, has responded to input from military leaders and agency directors, and in 2000 brought in a new agency director. It is hoped that the new management can bring better network services to the warfighter. [Ref. 29]

1. Navy Communications History

From the early 1900s, the Navy relied on high frequency radio as the principal transmission medium for long distance communications. This situation began to change in 1963 when the Navy installed and tested SATCOM terminals aboard selected platforms in support of North Atlantic Treaty Organization (NATO) requirements at shore sites and on flagships. The Navy's early DSCS/Super High Frequency (SHF) SATCOM access supported afloat Fleet Commanders using jam-resistant (spread-spectrum/code-division multiple access [SSMA/CDMA]) mode of operation. This service provided a 4800 bps maximum aggregate, full-duplex capability, and Surveillance Towed Array Sensor System (SURTASS) asymmetrical frequency-division multiple access (FDMA) mode of operation. The afloat Fleet Commander capability was limited to a few medium data rate (1200-2400 bps) circuits with most of the C4I direct connectivity provided via low data rate (LDR) channels. [Ref. 28, p.13]

During Operation Desert Shield/Storm, Navy C4I requirements increased significantly, saturating all available satellite assets. It was evident that additional satellite assets and capacity were required to support the Navy tactical mission and to provide a greater degree of joint and allied communications interoperability. The wide bandwidth and improved data rate (greater then 64 kbps) characteristics of DSCS/SHF SATCOM allowed SHF SATCOM to emerge as the best solution to provide the additional satellite capacity. In addition, the extent of C4I and war fighting communication requirements had accelerated. This

acceleration was due to both the number of users, to include aircraft carriers, cruisers, destroyers, and amphibious flag-configured ships; as well as the total aggregate of mission essential information exchange requirements. These requirements, coupled with the reduced Soviet threat, the use of larger, more capable SHF antennas and the use of demand assigned multiple access (DAMA), resulted in a change in operational philosophy. The change from jam resistant to an unprotected operating mode provided increased tactical service to the war fighter, as afloat SHF tactical terminal installations were expanded and Navy access to DSCS/SHF SATCOM increased. [Ref. 28, p.13]

Navy SHF SATCOM networks now provide afloat units with high capacity telecommunications trunks that are terminated at Naval Computer and Telecommunications Area-Master Station (NCTAMS) facilities. The transmission systems and the RF formats employed incorporate advanced bandwidth management features to enhance network operations. End user applications supported through SHF SATCOM systems fall in four general categories: command and control, mission planning/support, nontactical initiatives, and SURTASS.

a. Command and Control Applications

Command and control is supported via SHF SATCOM, primarily through full-duplex X-band circuits that provide secure telephone unit-third generation (STU-III) secure voice, and Global Command and Control System (GCCS) connectivity. In addition, the secure Video Information Exchange System (VIXS) and the Joint Worldwide Intelligence Communications System (JWICS) use SHF SATCOM to provide

video-based command, control, and intelligence support to the warfighter. Upon activation of the Global Broadcast Service (GBS), high bandwidth video circuits will likely migrate to virtual duplex architectures.

b. Mission Planning/Support

Mission planning and support functions are serviced at varying data rates via SHF SATCOM systems. In addition, the Joint Maritime Command Information System (JMCIS), the Joint Deployable Intelligence Support System (JDISS), and the Tactical Environmental Support System (TESS-3) are supported via X-band full-duplex SATCOM links. Upon activation of the GBS, high bandwidth imagery dissemination circuits will likely migrate to virtual duplex architectures.

c. Nontactical Applications

Logistics, administration, training, and online technical assistance are some of the nontactical applications served by SHF SATCOM systems. The Streamlined Alternate Logistic Transmission System (SALTS) is the largest nontactical user of this service, while medical and Public Affairs Office (PAO) Video Teleconference (VTC) applications are the largest nontactical users of SATCOM services. In addition, desktop VTC is an emerging nontactical application that may be served primarily through SHF SATCOM links.

d. SURTASS

SURTASS is a Navy user of DSCS/SHF. It is a worldwide system of platforms that tow passive acoustic sonar arrays. The shipboard SHF terminal used for this program is the AN/WSC-6(V). It passes data collected from

the sonar arrays via DSCS to the Naval Ocean Processing Facilities at Dam Neck, Virginia, or Whidbey Island, Washington.

2. Naval Communications Organization

Due to the vast operational environments in which the Navy operates, and the massive size of the organization, there are many separate departments within the Navy tasked with identifying, supporting, and planning for new and existing communications technologies. The Space and Naval Warfare Systems Command (SPAWAR) works directly for the Chief of Naval Operations (CNO). SPAWAR's mission is to provide the warfighter with knowledge superiority by developing, delivering, and maintaining effective, capable and integrated command, control, communications, computer, intelligence and surveillance systems. While their name and organizational structure have changed several times over the years, the basic mission of helping the Navy communicate and share critical information has not. SPAWAR provides information technology and space systems for today's Navy and Defense Department activities while planning and designing for the future. Within SPAWAR is the Communications Programs (PD-17) branch, and within this are the Program Manager Navy Satellite Communications (PMW-176), and the Program Manager Advanced Automated Tactical Communications (PMW-179). PMW-179 is the program manager for ADNS, and has named the USCG/USN ADNS project AN/USQ-144F (Version 2). [Ref. 30]

3. Future Applications

Navy commanders have necessitated a reevaluation and realignment of the means available to satisfy Naval circuit

requirements. This has come about because of the desire to provide cost-effective solutions that support the increasing communications information transfer needs of afloat assets. Navy SATCOM programs are being refined to meet these needs by funding research and development in the areas of IT and communications enhancements.

a. IT-21

The dawn of the information age, coupled with shrinking resources, are driving IT to become the force multiplier for the 21st century (IT-21). IT-21 is a Fleet Commander in Chief (FLTCINC) initiative to fundamentally transform the way DON plans and budgets for information technology (IT) acquisition. The Navy mind-set has shifted from acquiring IT as a centralized large-scale system, to considering IT as a disposable commodity. IT-21 is not a program, it is a strategy to optimize IT acquisition across all DON, involving extensive coordination between the many DON programs involved with fielding IT infrastructure. This IT-21 strategy is based on a two-step process:

- a global DON networking architecture to ensure interoperability
- IT acquisition solutions based on best business case analysis within each regional area.

IT-21's key enabler is "*smart-sourcing*", or the selective outsourcing of the underlying IT infrastructure. The IT infrastructure is viewed as an electronic commodity with warfare and warfare-support overlays. This involves extensive use of web technology to manage data and produce data. The structure will take advantage of commercial TCP/IP-based client server environment with multi-level

security standards. It will also merge tactical and non-tactical data on a common infrastructure. IT-21 is expected to be the key to more rapid fielding of "current" IT and enhanced business process reengineering (BPR) improvements. This is seen as the only way DON can afford to be on the leading edge of technology in the information age. [Ref. 31]

b. Copernicus Architecture

The Copernicus Architecture involves a major restructuring of Navy C4I to put the warfighter at the center of the command and control universe. The Navy has attempted this by striving to provide the supporting information that is needed, when it is required. The Joint Maritime Communications Strategy (JMCOMS) provides the technical and implementation strategy for the communications portion of Copernicus. JMCOMS technical thrusts are designed to introduce systems that facilitate the collection, correlation, and fusion of data. This is done to produce and efficiently disseminate information that is required by the joint task force (JTF), and joint task group (JTG) commanders in a format that can be readily used.

The Copernicus Communications Support System (CSS) relies upon the separation of the existing and planned users from direct access and control of the set of radio frequency assets available on each platform. It "inserts" a software/hardware "framework" between the users and the communications systems, and provides multi-link communications services to the collection of communications users. A cornerstone of this concept is that the

communications users are not aware of the media employed to transfer data to or from other users. Nor are they aware of the data rate, coding mechanisms, link protocols, or timing relationships. The users regard the CSS as only providing the communications services, which are specified in terms of distribution, security, quality, timeliness, and throughput. [Ref. 3, pp.I, II]

c. Challenge Athena

Another important program that the Navy is putting to use is called Challenge Athena. Challenge Athena is a commercial broadband satellite application utilized onboard large US Naval ships, and Intelsat provides the service. This program was encouraged because mission requirements drove Battle Group (BG) Commanders to seek larger bandwidth capacity. This bandwidth capacity was not available through the Department of Defense assets. Challenge Athena is a full-duplex, high data rate (1.544 Mbps) communications link (C/Ku wideband) capable of providing access to high-volume primary national imagery dissemination for large ships. This includes intelligence database transfers; video tele-conferencing, tele-medicine, tele-training services; and various other computer data systems. This is also the backbone for the Defense Information Support Network (DISN) and joint interoperable networks including JWICS, Secret/Unclassified Internet Protocol Router Networks and Air Tasking Order/Mission Data Update (ATO/MDU) transmissions. For the smaller Navy ships, less then 250 feet in length, Challenge Athena system uses commercial satellite channels (INMARSAT) and COTS/NDI to augment existing and extremely overburdened military satellite communications systems.

Current funding provides Challenge Athena terminals to approximately 40 Joint Task Force command-capable ships by FY 2005. Concurrent with this effort is the extension of medium data rate connectivity to other accompanying surface warships, amphibious assault ships, and logistics support ships via a battle group IT-21 wide area network. This network will eventually provide these capabilities to all Navy ships. Future transponder leasing programmatics are being evaluated. [Ref. 32]

d. Global Broadcast Service

Joint tactical operations require high-speed, multimedia communications and information flow for deployed, in-transit, or garrisoned forces, including lowest-echelons and small users. In late 1997/98, in an effort to ease the burden on the already overtaxed MILSATCOM infrastructure, this jointly funded project was undertaken within DoD. The Global Broadcast Service (GBS) would go on to augment and interface with other communications systems to provide a continuous, high-speed, one-way flow of high-volume information. This link would support routine operations, training and military exercises, special activities, crisis, situational awareness, weapons targeting, and intelligence. The GBS would revolutionize communications with increased capacity, faster delivery of data, near-real-time receipt of imagery and data to the warfighter, and reduced over-subscription of current MILSATCOM systems. The GBS also provided the capability to quickly disseminate large information products to various joint and small-user platforms. [Ref. 33]

e. Automated Digital Network System (ADNS)

One of the latest technologies being employed by the Navy is the ADNS. The ADNS provides timely data delivery service to and from all data user resources, and is being utilized on smaller vessels and submarines. The development of ADNS is based on the incorporation of COTS and Government Off-The-Shelf (GOTS) hardware and software. This includes IP routers, Integrated Services Digital Network (ISDN), and Asynchronous Transfer Mode (ATM) switches. ADNS provides the following improvements:

- Furnishes autonomous, digital, interoperable, joint and secure LAN/WAN management and control for RF assets on demand to Navy deployed personnel aboard ships and at shore sites
- Ensures worldwide communications connectivity via the RF assets included in the Defense Management Report (DMR) and the Integrated Test Plan (ITP)
- Automates all communications systems and replaces several unique sub networks with a single integrated network hub
- Provides Integrated Network Management (INM) which resolves problems caused by overloading or underutilization of existing communications circuits, yielding a 4X increase in multispectrum throughput efficiency over legacy systems
- Applies NDI COTS/GOTS router, switching and packet data technologies, enabling reduced life cycle costs

ADNS comprises three functional elements: Integrated Network Manager (INM), Routing and Switching (R&S), and Channel Access Protocols (CAPs). The INM provides the flexibility to adapt communications to

available assets and mission priorities. The R&S subsystem provides the interface to users, and performs routing and switching of user data to available transmission circuits. The objective R&S subsystem includes a COTS IP Network (ISDN) and ATM switches. The CAP equipment manages data exchange over JMCOMS circuits and networks, monitors network quality of service, and reports loading and error conditions to the INM. [Ref. 34}

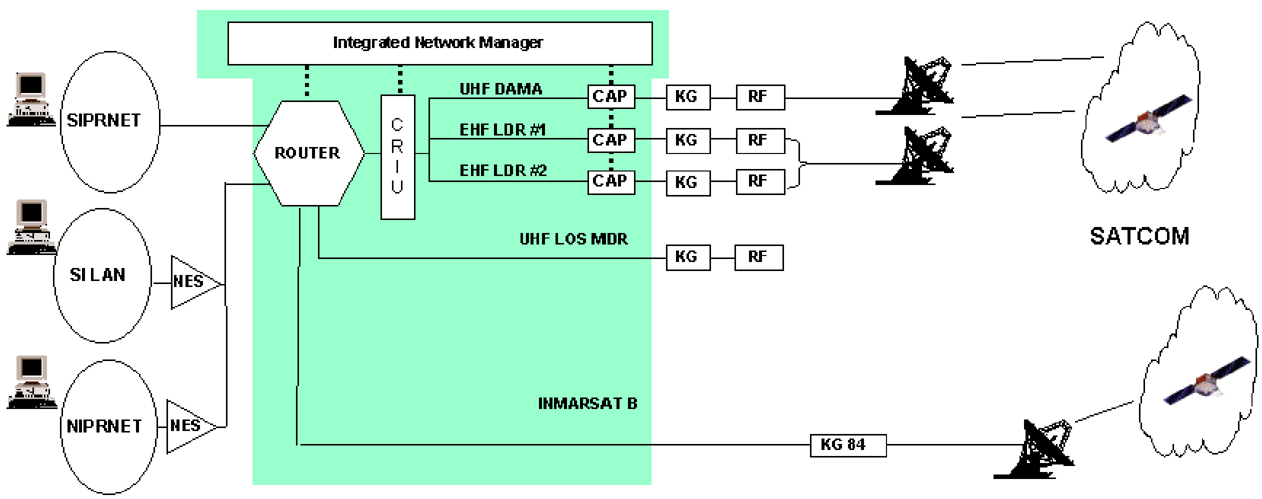

Figure 21. ADNS Build 2.0 [From Ref. 34]

ADNS integrates the GENSER LAN and Integrated Shipboard Network System (ISNS) LAN traffic destined for a CAMSLANT over a single IP link via a pier connection or SATCOM. This will be the way for Coast Guard ships to have VTC, file transfer, and DMS capabilities through a single link onboard CG cutters. It also enables voice and data transfer capabilities simultaneously. ADNS currently supports:

- Pier connectivity
- SHF
- INMARSAT-A
- INMARSAT-B
- INMARSAT-HSD

ADNS can operate at the Secret High General Service (GENSER) classification. Initially, multiple security levels from unclassified to Top Secret Special Compartmented Information (SCI) will be enforced by cryptographic separation using the Network Encryption System (NES). In successive builds, the Embedded INFOSEC Product (EIP) will replace the NES.

With the addition of ADNS to the INMARSAT channel, security is greatly improved. This may be the single most important consideration in the proposed adoption of ADNS. ADNS adds to the existing CG shipboard configuration, enhancing the current system with a secret router for the secret LAN, an FCC-100 multiplexer to provide simultaneous voice/data, TACLANE (encrypts unclas data to tunnel over SIPRNET), and 2 KG-84A's (one to encrypt the secret data, one to bulk encrypt everything coming off the ship) [Ref. 34]. ADNS adds two forms of US Government approved security, whereas current installations do not.

4. Navy/Coast Guard Interoperability

In order for the Coast Guard to be interoperable with the DoD, they will have to adopt IT-21 standards implemented by the Navy. In doing this the Coast Guard will not only guarantee open communications paths with DoD,

but they will be able to reduce research and development costs by working in unison with the Navy.

The ADNS configuration to be prototyped onboard CG cutter Dallas is dubbed “ADNS Lite”, because it is similar to configurations onboard Navy submarines and smaller Naval vessels. The ADNS configuration provides the CG a combination of capabilities enabling network centric operations, and future growth. While underway, this configuration will enable simultaneous access to the SIPRNET SECRET High network including web based services, CGDN+ UNCLAS network including web based services, and one dedicated voice circuit. [Ref. 35]

Figure 21 below depicts the hardware configuration onboard a USCG WHEC/WMEC with a lease INMARSAT-B channel. Much of the equipment used is standard DoD equipment for security and interoperability between networks. The TACLANE (KG-175) is short for Tactical FASTLANE and was developed by the National Security Agency (NSA). It was developed to provide network communications security on IP and ATM networks for the individual user, or for enclaves of users at the same security level. [Ref. 36] The KG-84A is a cryptographic device developed to ensure secure transmission of digital data. It is a Dedicated Loop Encryption Device (DLED), and is General-Purpose Telegraph Encryption Equipment (GPTEE). The KG-84A is primarily used for point-to-point encrypted communications via landline, microwave, and satellite systems. It is an outgrowth of the Navy HF communications program and supports those needs. This device is able to operate in simplex, half-duplex, or full-duplex modes. [Ref. 37]

These two security features offered by ADNS are huge improvements over the Coast Guard's traditional dial-up access methods. The traditional methods do not allow for US Government approved encryption, where as the ADNS equipment allows for two such encryptions. The last piece of the puzzle is the AN/FCC-100; it is a time-division multiplexer for voice, video, fax and data, allowing for simultaneous voice and data. [Ref. 38]

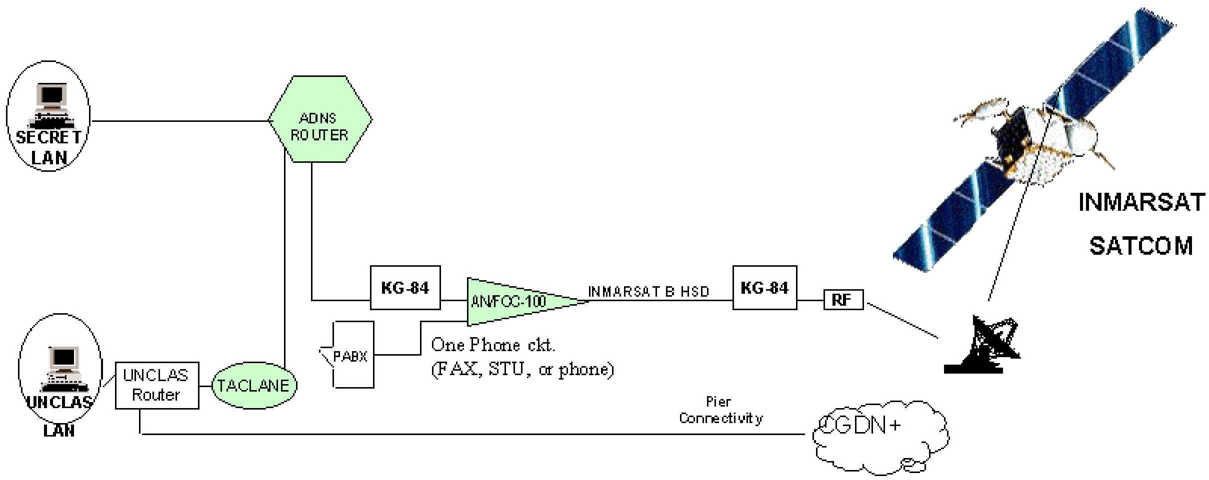

Figure 22. CG/ADNS Shipboard Configuration [From Ref. 37]

The next figure depicts the network configuration for the CG shore based ADNS. It shows how information from the ship is encrypted and sent to the USN NOC in Portsmouth, VA via the INMARSAT leased channel and the LES. The NOC provides access to the PSTN (for voice) and SIPRNET (for classified data). The UNCLAS portion of the data is "tunneled" via the SIPRNET line directly to the TACLANE located in the USCG CAMS where it is decrypted and sent to the CGDN+. The architecture is designed this way to remove

the Navy NOC from processing the UNCLAS portion of the IP bandwidth, and thus reducing the support burden on the Navy. Furthermore this will increase reliability and performance for CG cutters.

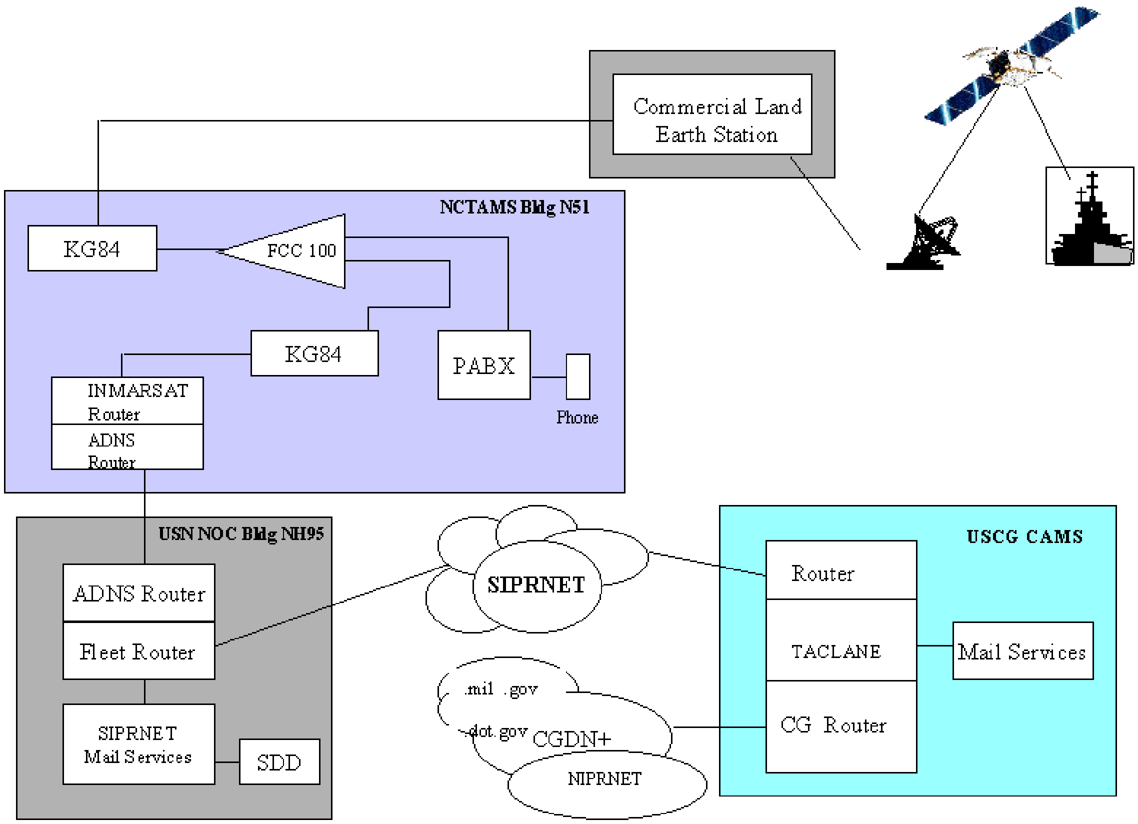

Figure 23. CG/ADNS Shoreside Configuration [From Ref. 37]

The shipboard physical diagram is as shown in the following figure:

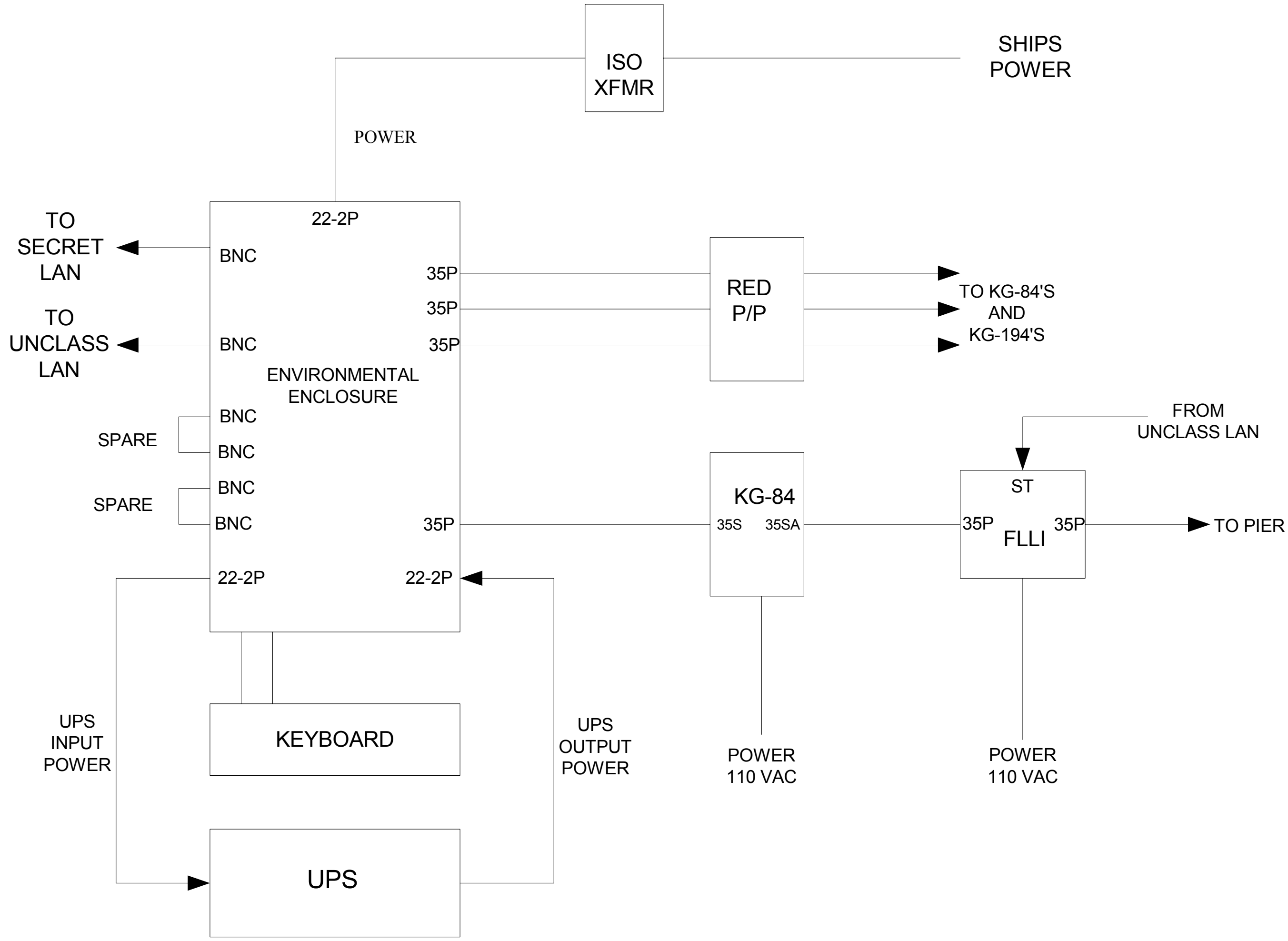

Figure 24. ADNS Physical Diagram [From Ref. 38]

By utilizing the Navy ADNS, the Coast Guard is eager to gain efficiency and faster data/voice transfer capabilities. This will be achieved while underway by the use of one dedicated phone line to be used for FAX, STU, or voice. Network access, SIPRNET and CGDN+, will simultaneously be achieved through an INMARSAT-B HSD channel. While pier side, CG cutters will have IP connections via standard phone line (T-1) connections to CGDN+ and UNCLAS lines. SIPRNET will be available through a pierside dial up connection only. [Ref. 35]

B. SYSTEM ANALYSIS

The Navy has been trying to overcome ship to shore communications problems for some time now. The Navy

operates much further from shore, and has a global mission that requires their ships to have reach back capabilities from virtually any body of water in the world. While the Coast Guard has been dealing with these same problems, the Coast Guard’s operational fleet is much smaller which narrows the problems they face with regard to engineering a successful communications architecture.

In order for smaller organizations to have communications interoperability with the larger ones, the smaller organizations need to adopt the larger ones’ standards. Thus, the Coast Guard needs to carefully consider what the Navy is putting to use. ADNS shows promise to be a great bandwidth allocation tool, with the versatility that the Coast Guard is looking for. This does not come cheap for either organization, though.

The following is an analysis of each of the 12 criteria identified in Chapter II for system comparison reasons. These are criteria the Coast Guard has identified as vital in regards to determining a successful communications system. Many of these criteria are the same as with INMARSAT, because ADNS uses the same channel, and is basically an INMARSAT efficiency tool.

1. Coverage

The coverage currently available to Coast Guard cutters will not change with the installation of ADNS, because the ADNS still uses INMARSAT satellite channels. What may change is the possibility that smaller cutters could see additional satellite connectivity. This would effectively increase the “network” of CG cutters connected, thus increasing the coverage area by the CG fleet.

2. Accuracy

INMARSAT is an inherently accurate system. By adding ADNS, this accuracy would not be compromised or improved.

3. Availability

Through the addition of ADNS, the Coast Guard would be increasing the complexity of the communications infrastructure. This is because all communications would first have to travel to Navy NOC/NCTAMS before being sent to the CG NOC. This would add possible complications if those Navy-operated stations experience equipment failures.

4. Cost

The Coast Guard cannot monetarily afford this implementation by itself. Thus the Navy initially agreed to help fund the some of the costs for prototyping and operational tests. The USN agreed to fund one ADNS installation in FY01 and two additional installations in FY02. They are also willing to provide the support and funding for services through Navy NOC's and NCTAMS. [Ref. 22] The N6 initially agreed to fund $102K for each of the USCG WHEC 378's, WMEC 270's, and WAGB 399's, but this proposal was rejected when introduced for the FY02 USN budget. Thus there is no funding for installations from the Navy at this time.

This poses a huge financial burden on the Coast Guard. Most significant is the lease of the 24 INMARSAT channels to provide the necessary bandwidth to share between underway vessels. This request was already removed from the FY02 budget, but the CG is hoping that future Deepwater developments will prove its necessity, and have the funding to support its purchase.

In addition to the purchase of dedicated satellite channels, the Coast Guard has additional obligations to fill. The CG had initially agreed to fund the remaining costs of the above-mentioned cutters at an approximate cost of $138K each, but this was also turned down in USCG FY02 budget requests. After most ADNS budget requests were cut from both Navy and CG FY02 budgets, the only funding is for one FY01 CG test platform and two FY02 test platforms.

The CG must take on the responsibility and financial obligations of annual funding for support and training once the service is operational. They must also purchase supplemental equipment suites to be installed at CAMSLANT and at three USN NOCs to provide for 20 simultaneous circuit terminations. All of this is a very expensive proposition for the CG, but is the first step necessary in order to provide the Nation’s homeland defense community with the necessary communications capabilities.

5. Interoperability

Adoption of ADNS, as well as other DoD standards will prove to be the best way for the Coast Guard to ensure interoperability. By adopting Navy standards, the CG can guarantee when the need arises, both departments will be able to share information with the least amount of hardship. Furthermore, this interoperability would be instantaneous, without the need for time and cost-intensive upgrades or changes to the existing systems. There will not be any need for retrofitting CG ships when deployed with Navy battle groups or during drug operations.

6. Latency

For reasons discussed in previous chapters, latency is still of great concern when dealing with the Navy ADNS. This system uses INMARSAT as its communications path, and therefore, has to overcome the extensive connection delays imposed by a geostationary satellite network.

7. Reliability

ADNS is a new communications solution for smaller Naval vessels, and it was briefly tested on a Coast Guard cutter prior to this writing. Only three days of underway testing were available, because of a three month scheduled drydock for CG cutter test platform. Thus further testing of ADNS will not be available till the DALLAS, the test platform, returns to normal operations. The brief period of testing showed no problems with the system and CG infrastructure interoperability or reliability. The Navy has seen dramatic improvements in communications capabilities on their smaller vessels and submarines after the installation of ADNS equipment. The Coast Guard should see similar gains.

8. Capacity

INMARSAT bandwidth is limited to 64 Kbps per channel. While ADNS does not expand that capacity, it does allow for much more efficient use of the channel. Without ADNS, one part of the channel may be exhausted while other parts remain free, but with the addition of ADNS equipment, this will not happen. ADNS will dynamically allocate bandwidth based on system needs and demands; all users will have access to the same channel.

9. Throughput

The ability to have all COMMS equipment required on the cutter to "talk" at any given time, without worrying about which antenna is hooked up, will greatly enhance the availability of the network. Again, this is due to the dynamic allocation capabilities of ADNS. During the brief testing on the Dallas, while the system operated without any problems, it was noted that the throughput seemed slower. This was probably due to the increased security measures that ADNS uses. Further testing will indeed be done when the DALLAS comes out of the shipyard. ADNS does provide simultaneous voice and data, which the CG Enterprise solution does not.

10. Ease of Use

Users will not even realize a difference in the use of their comms systems after ADNS is installed. Using ADNS on a shipboard configuration will only affect the last segment of the communications chain, before the signal is out the transmitter. Therefore, users will not have to be trained on a new system or have to deal with adapting to new software. The transfer to ADNS will be transparent to the end user. Furthermore, INMARSAT is already the communications standard onboard CG cutters and users are already familiar with the system.

11. Security

Use of ADNS will greatly increase the security of typical CG INMARSAT configurations. ADNS uses two DoD approved security features, the KG-84 and TACLANE, which are built into the ADNS. Currently, INMARSAT by itself does not have any DoD approved security features, so ADNS

provides huge security gains. Security is also improved by the access to the SIPRNET and Navy NOCs. This feature will enable classified information to travel over the INMARSAT connections, with two DoD security enhancements, thus enabling secure communications between CG cutters and Navy battle groups.

12. Maintainability

By implementing ADNS into the Coast Guard infrastructure, the CG could see additional maintenance requirements. This is because of the additional equipment that will be needed onboard the cutters and at the NOCs. Additional maintenance costs will be necessary to facilitate CG ADNS comms traffic through Navy NOCs and NCTAMS, as well as CG NOCs. Additional costs will be incurred due to the increase in comms traffic over the network, which could cause equipment to fail more often.

C. CONCLUSIONS

By combining SATCOM research efforts with the NAVY, both organizations will be able to reduce costs and increase interoperability. Implementing ADNS could prove a valuable addition to the largest CG cutters who might demand additional bandwidth. But implementation on smaller patrol boats would not prove feasible due to the size and cost. Before any implementation takes place though, a stringent examination needs to weigh the costs versus gains of such a system. Specifically taking into account new LEO technologies that may provide a better comms path then INMARSAT. These solutions could be available by 2005. It may not prove cost effective to install ADNS if INMARSAT is obsolete in three years.

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VI. ANALYSIS

The Coast Guard is a relatively small organization compared to the DoD forces, as such does not receive substantial funding to test and evaluate multiple communications systems sufficiently. The funding the Coast Guard does receive needs to be allocated toward mission critical functions such as keeping cutters afloat and helicopters flying. In addition, for the Coast Guard to adequately support Homeland Defense operations, it needs to have a robust SATCOM link to the terrestrial network infrastructure.

The INMARSAT network has provided this wireless medium with fairly good functionality in the past. During recent years though, the demands on this 1980's satellite technology have exceeded the system's design. The technology is not able to provide the data rates consumers are demanding. The maritime industry has had to do without the desired throughput their operations are now demanding. They often find themselves investing a great deal of money in keeping the system operational. There are technologies currently being developed which could theoretically provide more bandwidth and faster response times to meet current industry demands, but these technologies are in their infancy, and require much more funding and research.

A. SYSTEMS ANALYSIS

Throughout this thesis, the authors have presented two different technological solutions and one technology enhancement in an effort to show the capabilities and shortcomings of COMSAT connectivity for cutters underway.

GEO satellites were last year’s answer to wireless networking. Now, the LEO architecture is becoming the preferred connectivity solution. The authors have examined each of these systems to the same twelve criteria defined by the Coast Guard as necessary to achieve mission success. Future partnerships with the technological leaders will need to be enhanced to ensure the required security, throughput, and interoperability will be provided.

INMARSAT may be reaching the final years of adequate satellite functionality. With newer more advanced satellite communications equipment becoming available, the CG must decide whether to keep patching their older but established equipment they are already heavily vested in, or to fund development of new systems and implement them. With the current LEO advances in satellite communications, it would seem that geostationary systems might not be able to provide an adequate solution for much longer. This, of course, would force the Coast Guard and the rest of the maritime community into the decision of investing in a newer LEO network.

1. Twelve Criteria for Mission Success

In the following paragraphs we will identify the COMSAT systems that exceed, meet, or lack the performance characteristics required for that criteria. Because ADNS utilizes the INMARSAT channel for its communications path, whenever INMARSAT is stated as excelling in a specific area ADNS is also included as excelling in that area, but the opposite may not be true.

To aid in the comparison, we have included a table for each section and a summary table at the end of the

analysis, which represents a numerical report card of each system’s capabilities. This enables the reader to quickly and easily see what systems outperform the others. The authors have set standards for performance in a particular area that must be met in order for a COMSAT system to achieve a rank of 1, 2, 3, 4, or the best score of 5. This ranking structure can and should be used to compare future satellite technologies, so there is a common ranking and comparison structure used throughout the Coast Guard.

The lowest score of 1 means the COMSAT system cannot perform any of the stated mission requirements described in the performance criteria. A system may receive this score if, even with significant and system reengineering, the probability of meeting the performance criteria are virtually zero.

A score of 2 means the system still does not meet the minimum requirements as stated by the Coast Guard. But, it is known the system is capable of meeting the minimum requirements with additional funding and/or reengineering. However significant the alterations to the system, these changes will allow the system to meet the minimum requirements.

A score of 3 means the system, without alterations, meets the minimum requirements stated for operation. These are the minimums that the CG has identified to be acceptable for successful operation. By meeting these minimums, the system succeeds at the performance of that specific criterion.

A system that receives a 4 has proven it can provide the minimum requirements as stated, plus it can provide

additional features and/or capabilities within that criterion. These additional capabilities may come at additional cost or reengineering of the system.

The best score that a system can receive is a 5. This score reflects that the system's characteristics go above and beyond the minimum requirements. These enhanced capabilities are built into the system and require no further alterations of the COMSAT system.

a. Coverage

System	**Score**
Globalstar	4
INMARSAT	3
ADNS	3

Figure 25. Coverage Scores

All three systems can provide adequate operational coverage from approximately 70N to 70S. While the systems may not facilitate operations in the extreme polar regions, those operations are beyond the scope of this research. Globalstar received a mark of 4 with regards to coverage because of its path diversity technology. This technology allows multiple satellites and spot beams to provide a higher quality link. If one path is blocked by an obstruction, Globalstar can use a signal from a different spot beam or satellite to provide the strongest signal.

b. *Accuracy*

System	Score
Globalstar	3
INMARSAT	3
ADNS	3

Figure 26. Accuracy Scores

All systems meet the requirements for accuracy. The technology utilized today takes advantage of a link budget process that has very low bit error rates and few transmission failures. All systems also exercise forward error correcting coding. These techniques, when combined with proper network transport protocols, create a data network that is comparable to terrestrial network performance. One advantage the Globalstar system provides is the elimination of any perceptible delay during voice communications. This is a level of service that GEO systems cannot offer due to inherent latency issues. Adding ADNS to the INMARSAT channel will have no effect on accuracy.

c. *Availability*

System	Score
Globalstar	4
INMARSAT	2
ADNS	4

Figure 27. Availability Scores

INMARSAT will only achieve adequate availability once the CG purchases the necessary channels to support 24x7 communications. The Coast Guard has identified that 24 INMARSAT-B channels will be required to support operational requirements. In January and February of 2002, the CG did purchase six dial-up access channels and also utilized the Navy contractor, STRATOS, to lease twelve 64 kbps/100 kHz INMARSAT-B channels. These channels are on the commercial satellite located at 142W. This will only provide coverage for west coast operations, but the CG is pursuing efforts to migrate several of these channels to the 98W satellite for east coast coverage. The goal is for the CG to eventually have 24 leases with 70% on the 98W satellite. Figure 24 below shows locations of these two respective INMARSAT satellite locations. Orange delineates the 98W satellite coverage area, and green is the 142W satellite.

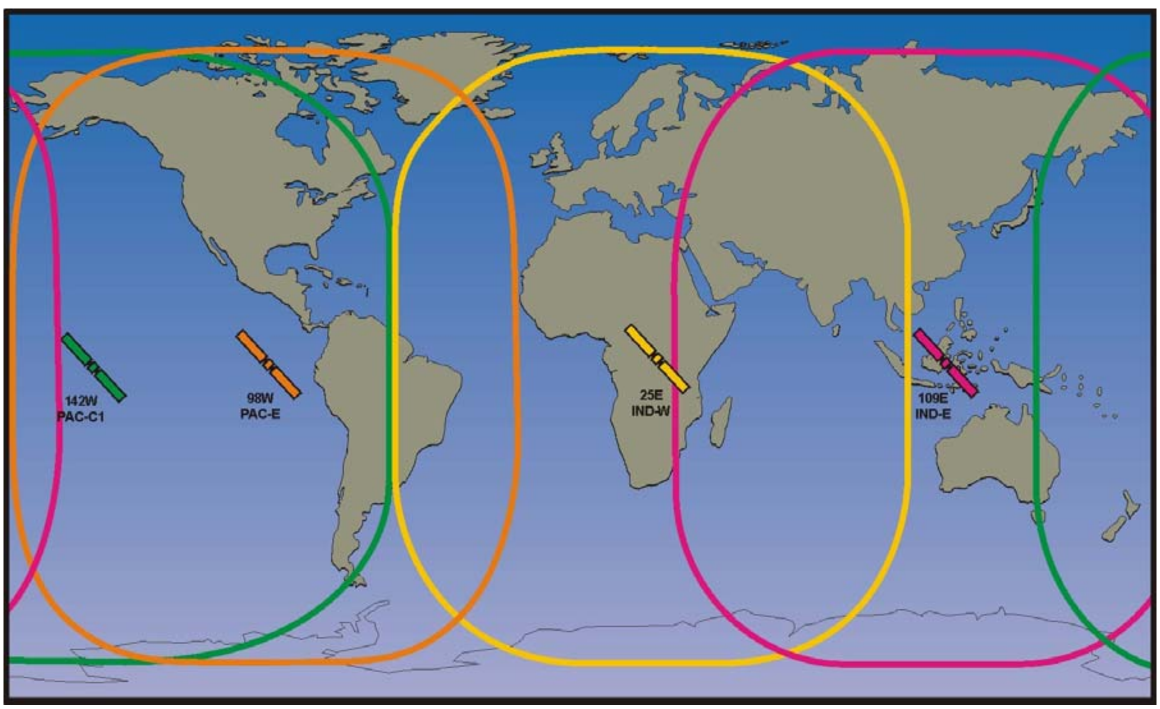

Figure 28. STRATOS Lease Map [From Ref. 37]

When all is said and done, it is not known if the 24 channels will provide adequate availability. More importantly, it is not known if the additional channels the CG needs will be available when the CG desires to lease them.

Globalstar meets the minimum requirements for availability. It also provides additional capabilities to the network. Aside from the satellite architecture, Globalstar can also utilize traditional cellular networks. This works to provide additional availability to the network. This capability is hindered by the limited offshore coverage of cellular networks. Routinely, coverage is only available 10-15 miles offshore and only near major metropolitan areas. This is often suitable for many of the coastal homeland defense operations.

ADNS meets the minimum requirements for availability. It also provides additional availability characteristics by more efficient use of bandwidth allocation tools. Additionally, ADNS provides the ability for simultaneous data and voice transmission.

d. Cost

System	**Initial Cost for 10 units**	**Monthly for 10 units**	**3 year cost for 10 units**	**Score**
Globalstar	$50K	$350K	$12.6M	3
INMARSAT	$500K	$3.9M/$160K	$140M/$5.8M	1/2
ADNS	$2.3M	$160K	$5.8M	2

Figure 29. Cost Scores

The above table demonstrates the costs associated with outfitting 10 operational units with a 24x7 network connection. These estimates are consistent with an average costal homeland defense force package at the CG district level of enforcement. While all three systems have varying levels of cost, Globalstar offers the solution with the least implementation cost and the most flexibility. However, utilizing a 24x7 network connection, Globalstar’s three-year lifecycle costs are more expensive than the other two systems. This three-year cost is a worst-case scenario and will most likely be significantly reduced during actual operation. The coastal units are often only deployed for several days at a time. Globalstar’s offering of a per-minute rate allow for some costs savings when a satellite connection is not demanded. This flexibility works well with the operational schedule of the smaller CG units.

INMARSAT also provides a per-minute rate for usage. However, its rate is significantly more expensive. This rate is represented by $3.9M for monthly access in the table above. The second number, $160K, is the cost of 10 leased channels. This equates to the system being cost prohibitive except when a leased channel is accessible. By leasing channels, both the monthly rate and the three-year lifecycle costs are significantly reduced. However, the smaller units will not use the leased channels as efficiently as a longer deployed unit. Much of the bandwidth will remain unused when the smaller units are not underway. An additional problem for this solution is the limited number of channels available for lease.

ADNS provides the lowest three-year lifecycle costs; however, it may prove difficult to implement due to its high initial costs of $230K per unit. ADNS implementation is further hindered by its demand for leased INMARSAT channels. As mentioned above, these leased channels are in limited supply.

The lower implementation costs, when coupled with the sporadic schedule of the coastal units, make Globalstar the most cost effective solution.

e. Interoperability

System	Score
Globalstar	3
INMARSAT	3
ADNS	4

Figure 30. Interoperability Scores

All three systems meet the interoperability requirements. INMARSAT has the best qualities for interoperability with the Navy and the maritime community. Globalstar does not provide the emergency characteristics that are required by GMDSS, and therefore could not be the single solution for maritime operations at the present time. Globalstar does offer dial-up connections to the PSTN and utilizes packet switched techniques, which will allow CGDN+ access through a VPN. Changes would have to be made at a NOC for Globalstar accessibility to SIPRNET, but this should not prove difficult or overly expensive. ADNS received a score of 4, as it provides the SIPRNET

connection without additional system configuration and expenses.

While all three systems provide adequate interoperability, ADNS provides the best solution for interacting with the US Navy and other DoD forces.

f. Latency

System	Score
Globalstar	4
INMARSAT	2
ADNS	2

Figure 31. Latency Scores

Both INMARSAT and ADNS utilize a GEO satellite architecture. This causes increased system latency, which adversely impacts the system's capabilities. The common networking protocols employed by the CGDN+ and other terrestrial networks do not allow for the significant latency inherent to a GEO satellite architecture.

Globalstar has the best characteristics for minimizing latency. Its transmission times more closely compare to those of the terrestrial network, and thus conform to TCP/IP standards. As any satellite constellation gets closer to earth, its signal latency will also be less, and the theoretical transmission capabilities will be greater. INMARSAT cannot, and never will be able to provide the low latency qualities that Windows and TCP/IP protocols demand. As data transfer demands continue to increase, the importance of low latency will also

increase. This is because of the inherent characteristics of TCP/IP protocols and the receiving window size limitations. This especially becomes apparent when the channel experiences delays due to errors and security requirements.

Globalstar received a mark of four because it not only meets the networking latency requirements, but also provides a connection without any perceptible delay for voice communications.

g. Reliability

System	Score
Globalstar	3
INMARSAT	3
ADNS	3

Figure 32. Reliability Score

INMARSAT has been providing the maritime community with reliable service for years. Globalstar has been used mostly in land-based applications (non maritime) and phone operations. There is no evidence to expect that Globalstar could not provide the same reliability as INMARSAT. Globalstar has been effectively utilized in remote areas of the world for Army/Marine Corps communications. By drawing from their experiences, it is the authors' opinion that the same QoS would be experienced at sea.

h. Capacity

System	Score
Globalstar	2
INMARSAT	2
ADNS	2

Figure 33. Capacity Scores

Globalstar received a mark of 2, as its 9.6 kbps per channel does not meet the bandwidth requirements for the CG. To meet minimum bandwidth requirements of 128 kbps for CG use, a minimum of 13 of these channels would have to be purchased and multiplexed. Recent developments by Qualcomm, though, have proven 128 kbps capabilities with an aircraft application, but have not been tested for maritime use. Qualcomm currently has no impetus for maritime applications. The CG needs to contact Qualcomm concerning the design and development of a robust maritime solution. By partnering, they will be able to assure a successful network architecture that will be able to expand when new demands arise.

ADNS and INMARSAT also received a mark of 2 as they can only provide approximately half of the required 128 kbps. Further research into the feasibility of INMARSAT capacity expanders could prove to achieve the desired bandwidth on a single INMARSAT channel. However, these solutions will likely suffer losses in other areas (accuracy, security). These devices, used in conjunction with ADNS, could provide the most capacity for a satellite system available for use on only the largest of CG cutters.

For the smaller patrol boats, ADNS is not an option due to the cost and size. INMARSAT Mini-M would have to be utilized, and thus the capacity of only 9.6 kbps could be achieved. None of the three SATCOM solutions can meet the minimum requirements in this area.

i. Throughput

System	Score
Globalstar	2
INMARSAT	2
ADNS	2

Figure 34. Throughput Scores

A single Globalstar channel has shown an effective data rate of 7.4 kbps on their 9.6 kbps system, which is 23% less than the stated rate. This reduction is a result of the overhead required to be transmitted with each packet. INMARSAT and ADNS have similar effective data rate losses. Currently CG cutters are experiencing an effective data rate of 44.3 kbps for INMARSAT over a single 64 kbps channel. Routing, address and header information will consume approximately 15% of the data packet. Security and other miscellaneous information will consume approximately another 15% of the same packet. Thus, non-data items take up 30% of our original optimal capacity of 64 kbps.

While the effective data rates may be higher, GEO communication systems will not be able to offer the throughput capabilities of a LEO system. For this reason,

the majority of the satellite networking industry is migrating toward the LEO satellite architecture. Comparing the propagation and transmission delay of a Globalstar (LEO) and INMARSAT (GEO) using a 2-kilobit packet demonstrates the effect of the delay.

Consider the transmission of a 2-kilobit packet transmitted over the INMARSAT system. This 2-kilobit packet, when divided by the 44.3 kbps data rate, equals a 45 msec transmission time. When this transmission time is added to the 500 msec propagation delay incurred by a GEO system, a total time delay of approximately 545 msec results. If throughput is simply defined as the amount of data divided by the time to deliver a packet, then 2000 bits divided by 545 msec reveals a throughput for INMARSAT of only 3.7 kbps.

In contrast to the GEO system, a LEO system only incurs a propagation delay of approximately 4 msec and a transmission delay of 270 msec. Using the same computations as above reveals a throughput rate for Globalstar of 7.3 kbps, nearly double that of INMARSAT. This proves that the throughput of a GEO system cannot compete with that of a LEO due system do to the latency incurred by the system and regardless of the system’s capacity.

By using ADNS, throughput can theoretically be improved. This is because voice and data can be transferred simultaneously, thus increasing the current throughput of INMARSAT alone. However, ADNS is still constrained by the large delays incurred by a GEO system.

As shown above, none of the three systems meet the requirements for throughput and thus receive a rating of 2.

j. Ease of Use

System	Score
Globalstar	3
INMARSAT	3
ADNS	3

Figure 35. Ease of Use Scores

All systems were given a mark of 3 as they can be easily used with traditional laptop/desktop computers or the CG standard workstation III. INMARSAT has been used in the CG fleet for several years, so the networking infrastructure as well as personnel training is familiar to the CG. Globalstar can connect to a PC through the Globalstar phone for data transmission; therefore, Globalstar should prove easy to use. All three systems meet the CG requirements for ease of use.

k. Security

System	Score
Globalstar	3
INMARSAT	1
ADNS	4

Figure 36. Security Scores

ADNS provides the best security features to meet future homeland defense operational needs. ADNS will

drastically improve the level of security the CG has been operating with, and security needs to be improved as the threat to our homeland has increased. ADNS adds two levels of government-approved encryption. This alone may prove reason enough to add ADNS to current INMARSAT systems on the CG's larger cutters.

INMARSAT received a mark of 1 and should be considered a severe security risk. INMARSAT does not utilize any government approved encryption techniques and should be viewed as a threat to CG operations. Currently, INMARSAT cannot meet the new demands for security on government networks as a result of September 11th.

Globalstar has external equipment that provides end-to-end Triple-DES encryption. This is greater than that offered by INMARSAT. This encryption is in addition to the inherent security characteristics of Globalstar's CDMA technology. Globalstar also offers government-approved link level encryption and thus warrants the score of 3.

l. Maintainability

System	Score
Globalstar	3
INMARSAT	3
ADNS	3

Figure 37. Maintainability Scores

All systems provide an easily maintainable solution for satellite communications. They all maintain

redundant satellites in orbit. However, Globalstar is a more redundant system as it maintains a larger constellation. On smaller CG vessels in support of homeland defense, Globalstar's hand-held phones may provide for a best solution. These will provide a very maintainable solution for a small vessel that is often not away from port for very long. This phone can connect to PC's for data transfer, and does not require any antenna equipment to maintain. When considering the maintainability of satellite solutions, there also needs to be much consideration for the maintenance of NOCs, not just the ships. By using ADNS CG personnel might have to maintain additional CG assets at Navy NOCs, as well as additional equipment at their own NOCs.

B. SUMMARY

Based on the preceding research, we have analyzed three possible communications solutions available to the CG immediately. The following table shows how these different systems compare to each other for each criterion.

	INMARSAT	Globalstar	ADNS
Coverage	3	4	4
Accuracy	3	3	3
Availability	2	4	4
Cost	2	3	2
Interoperability	3	3	4
Latency	2	4	2
Reliability	3	3	3
Capacity	2	2	2
Throughput	2	2	2
Ease of Use	3	3	3
Security	1	3	4
Maintainability	3	3	3
Average	2.42	3.08	3.00

Figure 38. System Rankings

This analysis allows easy comparison of these satellite solutions. By looking at the table, it is quickly discernable that INMARSAT is lacking performance in the areas of cost, security, and capacity. These three are arguably the most important to the future success of CG communications and homeland defense. INMARSAT also has the lowest overall average of 2.42, which shows that the overall system does not perform to the minimum CG requirements.

In looking at the Globalstar column, it is easy to see that the system characteristics more closely match the Coast Guard’s requirements. Globalstar outperforms INMARSAT in 5 areas. The Globalstar network excelled in three key areas of coverage, latency, and availability. Although the Globalstar network currently lacks the single channel capacity desired by the CG, its throughput capabilities greatly exceed that of INMARSAT or any GEO system. These again are extremely important factors for mission success, and channel capacity must be addressed before a Globalstar solution can be implemented. By multiplexing channels of Globalstar, a user will be able to far exceed the capabilities any GEO system will ever be able to offer. The average for Globalstar is 3.08, the highest overall average of the three systems.

ADNS improves INMARSAT’s capabilities in four of the areas (coverage, security, interoperability, and availability), but does worse in one category (cost). ADNS, by excelling in the areas of security and interoperability, may prove mandatory for success on the larger CG platforms. The CG needs to look closely at these

areas. It must determine if the additional costs will be worth the gains in the areas of coverage, security, availability, and interoperability. The latency characteristics still unfavorably affect the ADNS system, and limit the potential throughput of the channel. ADNS received an overall score of 3.0.

No solution is going to perform optimally in all areas for successful implementation on all CG platforms. Therefore, careful analysis needs to be conducted in order to identify the most important criteria. The authors of this thesis believe there are four main requirements that should receive the heaviest consideration. These four are considered to be mandatory for patrol boats in support of homeland defense: coverage, cost, throughput and security. Table 17 below shows how the three satellite networks compare when only considering those four criteria.

	INMARSAT	Globalstar	ADNS
Coverage	3	4	4
Cost	2	3	2
Throughput	2	2	2
Security	1	3	4
Average	2.0	3.0	3.0

Figure 39. Four Critical Criteria

By looking at this table, the averages shift in favor of ADNS and Globalstar, and reveal INMARSAT as a severe under-performer. However, ADNS is not yet a feasible solution for implementation on CG patrol boats due to size, weight, and cost limitations. This makes Globalstar the most favorable solution, especially when the comparison is made to the INMARSAT Mini-M equipment, and its lack of

security and throughput capabilities. Globalstar will further excel when its 128 kbps throughput aircraft solution can be optimized for maritime use.

Each of the analyzed solutions provides technological claims in different areas. INMARSAT, while not an overachiever by any means, has a long and successful reputation. Adding ADNS to the system will improve four of the six criteria that INMARSAT is lacking in, but it will have a considerable negative impact on the budget. These improvements will need to be further analyzed for the larger ships as to the necessity of the capacity and security needed for mission success. Currently Globalstar is on the verge of making a 128 kbps solution available which will make this system a clear winner. It would be in the CG’s best interest to start adopting this technology to prepare itself better for a fleet wide LEO migration.

VII. CONCLUSION

The current maximum bandwidth of INMARSAT has already been identified as not meeting the minimum requirements for Coast Guard operational success. With the use of capacity expanders, the minimum capacity identified by the CG can theoretically be met, but CG communication demands are in their infancy stages and will likely grow. This puts the CG in the difficult situation of heavily investing in a sub par technology. As shown by the research in this paper, there currently is no wireless technology that can meet, let alone excel, in performance of the 12 identified criteria. Not only will these demands grow by an exponential rate, but more solutions will become available that will have to be analyzed for possible utilization.

From our research, Globalstar is the best overall performer. It offers the ability to simultaneously transmit and receive voice and data. This is a great advantage over the standalone INMARSAT channel. Globalstar also offers the ability to double encrypt the traffic that is traveling over the network, again, a significant advantage over INMARSAT. Most importantly the Globalstar solution is small enough to be effectively utilized by the CG's patrol boats. This can be done at a significantly reduced cost compared to the dial-up cost that the CG is now incurring. It has greater security, lower initial costs, and the best availability, but currently in single channel mode it lacks the necessary bandwidth. While this is a crucial issue, there is a product being tested by Qualcomm, which will enable aircraft to have wireless

communications at 128 kbps. It will also soon be tested onboard vehicles for the military. In talking with the engineers of this technology, it seems that it would be fairly easy to adapt it to the maritime environment. It may be in the CG's best interests to begin a partnership with the Qualcomm team, to better mold this technology so it can soon become a total solution for the maritime industry.

With that being said, only INMARSAT supports GMDSS, and that is the mainstay behind the maritime community. It is backed by 20+ national governments, and will not likely be replaced in the near future. Nevertheless, with the pace of technology today, an open-minded look needs to be taken at the cost of maintaining a 20-year-old satellite system with a new, more robust wireless network. How much longer can these organizations afford to put patches on this system whose capacity is fast being exceeded?

Research needs to be focused on developing solutions to allow GMDSS signals the ability to travel over multiple networks, thus making it more robust and redundant. The maritime community must be willing to fund and support new systems, to allow these advances. Also, consideration needs to be made whether this should be another joint venture by a multinational organization, or will the Teledesics, Skybridges, and Globalstars of the world be able to handle the maritime demands. These are all hurdles that need to be overcome before the Coast Guard can move away from the INMARSAT technology. Whatever the conclusion, it needs to be assured that the network is modular in its architecture so it will easily be able to

grow and expand with the changing demands of the maritime industry.

While interoperability has focused on other law enforcement agencies or DoD, the Coast Guard cannot forget their most important partner, the public. In the process of upgrading the communications infrastructure, the Coast Guard needs to recognize that most recreational mariners only have cellular phones or VHF radios for distress and communications needs. Coast Guard cutters and aircraft will need to maintain these communications capabilities to ensure they are able to respond, communicate and facilitate operations involving the public boating community.

The authors would like to reiterate several of the key conclusions this research has provided.

- The latency incurred by a GEO satellite architecture severally impacts the performance of the system. For this reason, future technology will migrate towards a LEO architecture.
- The CG needs to pay close attention to a system’s throughput, not the mere system capacity.
- The CG must reevaluate its current systems with regards to security. INMARSAT does not provide adequate security for operational use.
- The CG must establish strategic partnerships with industry leading companies in order to integrate new technology into both its current and future architectures.

A. RECOMMENDATIONS FOR FUTURE RESEARCH

Many facets of the Coast Guard operations and communications arenas need to be further researched to adequately support a growing satellite based network system. Most notably would be security and interoperability. What information can travel in the

clear, what cannot, who/what does the CG need to connect to that requires a secure connection? What standards do those agencies use that the CG must also use in order to communicate effectively.

More research needs to be done to find effective bandwidth allocation tools, such as what the Navy calls Demand Assigned Multiple Access (DAMA). Priority needs to be given to certain information in order to ensure its timely transmission. This area needs to be further explored to improve efficiency and reliability of future systems. The Navy and commercial companies have done much research on this topic, and possibly these solutions would also work for the Coast Guard.

Security is also a known problem with wireless systems. Electronic signals can be traced, intercepted, altered and jammed. Adding security to thwart these efforts adds data to the transmission, thus taking up precious bandwidth. There are already government-approved and commercial solutions available, and the Coast Guard needs to take advantage of them.

B. SUMMARY

The importance of the Coast Guard’s coastal defense and SAR missions has lately been emphasized as a result of the attacks on September 11th. At no time in history have these facts been more evident to Congress and the President than now. Since September 11th, the Coast Guard has been called upon to increase container and vessel inspections and increase port security patrols including boarding and riding of every cargo ship into port. These increased

operations are done in addition to the duties CG personnel are already performing.

In order to perform these duties Coast Guard personnel need the support of a robust communications architecture. Three of the most important aspects of this architecture are the need for interoperability, adequate throughput, and security. While performing Homeland Defense operations the Coast Guard will be working in conjunction with FBI, DEA, INS, as well as DoD forces. Thus the need to communicate with them over a secure network will be vital. Wile most of these near shore operations will allow for VHF voice communications, they will not allow for adequate data or video transmissions. Consequently, the Coast Guard finds itself trying to keep up with the fast pace of changing communications in order to be able to communicate with these agencies.

In the next five years many new LEO satellite communications systems are to be operational. Many of these, including Teledesic's "fiber in-the-sky", promise to provide terrestrial network capabilities through satellite connections. The CG will realize that neither this, nor any other solution, alone will be able to solve all the CG's communications problems. Due to the diverse operational requirements, different CG assets will only afford or require the use of specific transmit/receive equipment. The CG 87' patrol boat may not necessarily need a 1MB connection, but will most likely need secure voice and maybe a 64 kbps data connection. The CG will need to invest in communications equipment that will enable each asset to communicate with a central, terrestrial based NOC.

From there they should be able to connect to the CGDN+, SIPRNET, other multi-agency database previously set up for communication over wireless networks, or back out to another vessel or aircraft.

The satellite community is embracing LEO technology as the next, and only effective transmission path for data communications. By partnering with these LEO providers the CG can help to establish an effective network architecture for the maritime community. Qualcomm and other businesses are willing to put forward the effort to support the maritime industry’s needs, but only if the funding and buyers are there. By slowly investing in the LEO technology now, the CG will be able to implement the next generation of SATCOM technology in small doses. Doing this will prevent the CG from finding themselves as laggards, and not being able to communicate effectively with the rest of the maritime community.

During the time of our research and in writing this thesis, much was happening in the way of CG satellite connectivity. Commercial entities are fast to find solutions for areas lacking adequate communications. The CG cannot allow itself to be blinded by the latest technology, and “must have” solutions proposed by the industry. By keeping focused on their mission requirements and the tools necessary for the job, the Coast Guard will be able to ensure a quality solution will be found.

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